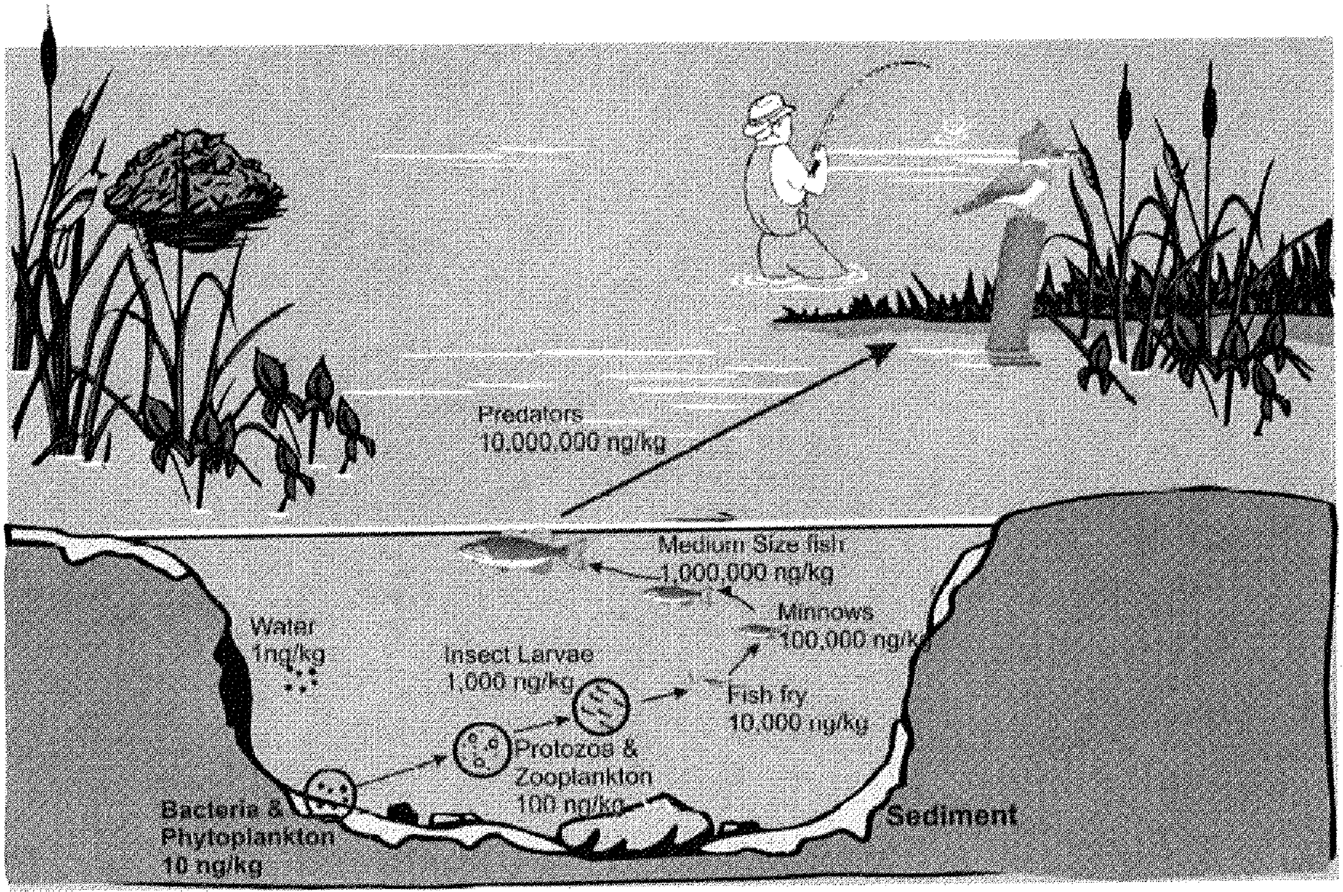
New Jersey Mercury Task Force

VOLUME I:
EXECUTIVE SUMMARY & RECOMMENDATIONS



Biomagnification of Mercury

December, 2001

Prepared for New Jersey Department of Environmental Protection

New Jersey Mercury Task Force Report
Volume I: Executive Summary and Recommendations

December 2001

New Jersey Mercury Task Force Report
Volume 1: Executive Summary and Recommendations

December 2001

New Jersey Mercury Task Force

Donald T. DiFrancesco Acting Governor	Robert C. Shinn, Jr. Commissioner

State of New Jersey
Department of Environmental Protection

Christine Todd Whitman
Governor

Robert C. Shinn, Jr.
Commissioner

Department of Environmental Protection
Commissioner's Office
401 East State Street, 7th Floor
P.O. Box 402
Trenton, NJ 08625-0402

Dear Reader:

Mercury is a persistent, bioaccumulative, toxic pollutant. An organic form of mercury (methylmercury) has been found at unacceptably high levels in certain fish, and can cause serious health effects in some fish consumers. Other exposure routes are also potentially important, including exposure to primarily inorganic forms of mercury in some private well water.

Through a combination of source reduction and aggressive pollution control measures, we in New Jersey, have achieved some very notable reductions in the environmental releases of mercury over the past decade including reductions in emissions from municipal solid waste and medical waste incinerators.

More significant reductions are feasible and necessary. The Mercury Task Force recommends a strategic goal of an 85% decrease in in-state mercury emissions from 1990 to 2011. (This goal equates to a 65% decrease from today to 2011.) At my request, the Mercury Task Force has diligently assembled a vast body of information to serve as the basis for a comprehensive set of recommendations to reduce the environmental impacts of mercury releases. These recommendations are designed to provide New Jersey with its first comprehensive mercury pollution reduction plan. Implementation of these recommendations will limit mercury exposures to our citizens and our wildlife.

I would like to thank all of the Task Force members for their hard work and dedicated service to the citizens of New Jersey, and I am pleased to accept this comprehensive Mercury Task Force Report. I urge legislators, government officials, the environmental community, business and industry, the scientific and technical community, and all other interested citizens to review this report and determine how they can most effectively work in partnership with the New Jersey Department of Environmental Protection and other state agencies, to achieve these important New Jersey mercury reduction goals.

Sincerely,

Robert C. Shinn, Jr.
Commissioner

E O H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES INSTITUTE

University of Medicine & Dentistry of New Jersey
Department of Environmental and Community Medicine
EOHSI Building---170 Frelinghuysen Road
Piscataway, NJ 08854
Phone 732-445-0123 X627 FAX 732-445-0130
email "gochfeld@eohsi.rutgers.edu"

November 2001

Commissioner Robert C. Shinn, Jr.
NJ Department of Environmental Protection
P.O. Box 402
Trenton, NJ 08625-04002

Dear Commissioner:

The members of the Task Force are pleased to submit to you our recommendations for reducing mercury impacts to the environment.

Mercury is a highly toxic material that has no known essential biological properties. It is toxic to adults, but the main health concern today is its potentially profound impact on the developing nervous system and the concern that fetal development can be significantly altered by even low levels of mercury (particularly methylmercury) in the mother's diet. This growing concern, spurred by recent epidemiologic research, has led many governments and other groups to address the problem of mercury in the environment.

Mercury's unique physical properties have led to its use for centuries in a wide variety of commercial applications and industrial processes. Its toxic properties have also been exploited in medicine, dentistry, agriculture, and paint manufacture. Although most uses have been eliminated or reduced (for example, mercury fungicides and batteries), or are being phased out today (for example, mercury thermometers), mercury remains in commerce in a number of forms including dental amalgams, fluorescent lights, thermostats, and certain electric switches.

Today, however, many of the most serious sources of mercury are inadvertent. These include the burning of waste, the use of coal to generate electricity, and the recycling of a variety of mercury-containing products, such as metals. Recognizing that toxic methylmercury occurred at surprisingly high levels in some freshwater fish from many waterbodies in the State, the New Jersey Department of Environmental Protection convened the first Mercury Task force in 1993. This advisory group concluded that emissions from municipal solid waste incinerators were, at that time, the main controllable sources of mercury emissions in the state. Its recommendations and subsequent regulations led to a major reduction in mercury emissions from New Jersey incinerators; the targets set by the first Task Force for this particular industrial sector have been met and surpassed.

It has been my privilege to chair the second Mercury Task Force, convened in 1998 by Commissioner Robert C. Shinn, Jr., which has tackled a much wider array of mercury sources. Triggered, in part, by the concern that energy deregulation would increase the output from midwestern power plants which, as a whole, have relatively high emissions including mercury, the Task Force had to grapple at the outset with recommendations to assure that New Jersey's own energy deregulation law would not exacerbate New Jersey's mercury pollution problem. The Task Force went on to inventory many other sources of mercury to the environment, some of them unanticipated.

Our work has been rendered at times easier, and at times more difficult, by the many reports from federal agencies, other states, non-governmental organizations, and public interest groups that have appeared during the lifetime of the Task Force. New Jersey is by no means alone in considering various approaches, including legislation, to reduce mercury uses and emissions. It has indeed been an exciting time to learn about mercury.

For three years now I have had the opportunity to work with and learn from many dedicated and knowledgeable Task Force members and NJDEP representatives. We have also benefited from the numerous presentations made to the Task Force by outside groups, each with unique knowledge and perspectives. They are identified in Appendix VI.

Work on a voluntary Task Force of this nature is extremely demanding of time and energy. A number of Task Force members and other stable participants were indefatigable in their participation, and I particularly want to thank:

William Baker
Andrew Bellina
Janet Cox
Daniel Cunningham
Robert Dixon
Tom Fote
Betty Jensen
Russ Like
Jerry Marcus
Leslie McGeorge (NJDEP Representative)
Keith Michels
Robert Morris
Joel O'Connor
Valerie Thomas
Robert Tucker

Also, Dolores Phillips played a very active role in the origin and early deliberations of the Task Force.

Many NJDEP representatives contributed to the research and writing of the report. All are listed in Appendix IV.

I particularly thank Bob Morris, Alan Stern and Michael Aucott whose time commitments to the Task Force were great and who each co-chaired one of the two working sub-committees (Impacts and Sources). Leslie McGeorge coordinated all NJDEP technical support for the Task Force, kept the Task Force focused on its charges and integrated its work with other NJDEP projects and programs. Sue Shannon coordinated various aspects of the Task Force and managed the communications and planning of meetings.

Other NJDEP staffers who made major contributions include:

Sunila Agrawal
Alan Bookman
Gary Buchanan
Robert Confer
Jim DeNoble
Mary Downes-Gastrich
Randy England
Joann Held
Mike McLinden
Eileen Murphy
Bill O'Sullivan
Anthony Pilawski
Bruce Ruppel
Michael Winka

I personally thank Commissioner Shinn for the thoughtful organization of the Task Force and his patience in awaiting this report. I trust that it will prove valuable in helping New Jersey and the Nation grapple with an insidious pollutant and reduce its impact on future generations. I echo his charge, that the lessons learned from mercury toxicity, mercury pollution and mercury control, should also help us in reducing human and ecosystem exposure to other environmental hazards which can threaten our growing population.

Sincerely yours,

Michael Gochfeld, MD, PhD
Chair

Charge to the Mercury Task Force
From Administrative Order 1998-08
Signed by Commissioner Shinn in March 1998

The mission of the Task Force is to develop a mercury pollution reduction plan for New Jersey. The Task Force is directed to complete the following tasks:

1. Review the current science on: a) impacts of mercury pollution on public health and ecosystems; and b) mercury deposition, transport, and exposure pathways.

2. Inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution.

3. Utilizing available information, quantify mercury pollution's impact on New Jersey's ecosystems, public health, and tourism and recreation industries.

4. Review New Jersey's existing mercury pollution policies.

5. Develop a mercury pollution reduction plan for the State of New Jersey, including:
   A) Recommend mercury emission controls and standards for in-state sources, including: coal fired generators; hazardous waste incinerators; sludge incinerators; hospital waste incinerators; and for other sources deemed necessary by the task force. In recommending controls and standards, the task force will explore renewable energy and alternative fuels to mercury emitting fuels now in use, and review innovative and low cost emission reduction strategies available in various industrial sectors.
   B) Provide timely interim recommendations, as feasible, prior to completion of the task force's overall mission, to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls and standards and the relationship of energy deregulation to mercury pollution.

NJ Mercury Task Force
Final Report

Volume I
Executive Summary and Recommendations

Volume II
Exposure and Impacts

Volume III
Sources of Mercury to New Jersey's Environment

Volume I

Executive Summary and Recommendations

Revised – 2nd Printing

Table of Contents

List of Figures

List of Tables

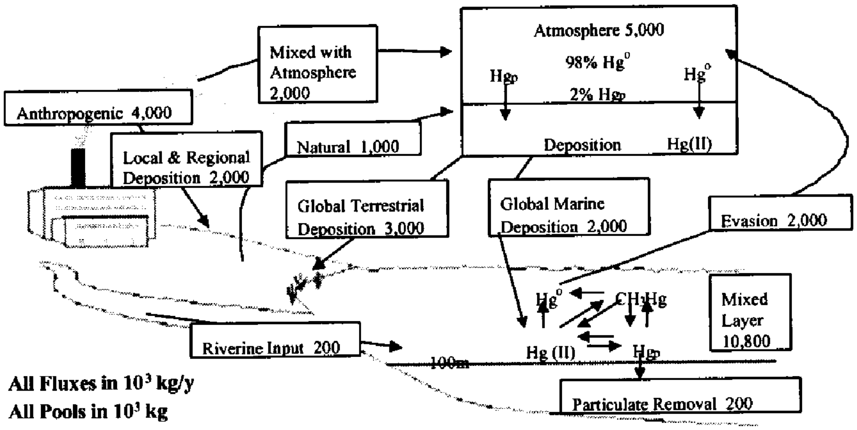
NEW JERSEY MERCURY TASK FORCE REPORT VOLUME 1: EXECUTIVE SUMMARY AND RECOMMENDATIONS

Introduction

Mercury is a highly toxic heavy metal with unique chemical and physical properties and no known essential biological function either for humans or for other organisms. Its unique properties have led to its use by humans in a variety of ways. Because of its broad spectrum toxicity, it has been used as an antiseptic and a pesticide. Mercury is a high density liquid metal at room temperature and has been used in a wide variety of mechanical and electrical devices including thermometers, barometers, pressure gauges, batteries and switches. Because it can form amalgams with other metals, it has been used extensively as a dental restorative and in the extraction of gold. Mercury also occurs as a naturally occurring trace contaminant in fossil fuels, particularly coal.

These commercial uses and the wide scale and long-term combustion of fossil fuels have resulted in the global dispersion of mercury and its occurrence in biologically significant concentrations in all environmental media. Figure 1.1 depicts the current global mercury cycle. In this figure, estimates are shown for source quantities, deposition quantities, and global inventories, or pools, of mercury. Flux quantities are in thousands of kilograms (metric tons) per year, and pool quantities are in tons.

Figure 1.1
The Current Global Mercury Cycle



Hg_p = mercury associated with particles
Hg^o = elemental mercury
Hg(II) = oxidized mercury
CH_3Hg = methylmercury
kg = kilograms
kg/y = kilograms per year

Adapted from: Mason, R.P., W.F. Fitzgerald, & F.M.M. Morel, 1994, biogeochemical cycling of elemental mercury: Anthropogenic influences, *Geochimica et Cosmochimica Acta.*, Vol 58, pp. 3191-3198.

Figure 1.1 shows that an estimated 50% of human-caused (anthropogenic) emissions deposit locally or regionally, and the rest join the global atmospheric pool. Natural emissions of mercury also occur. In the atmosphere, mercury exists primarily in the elemental form (Hg^o), although a small percentage exists adsorbed to, or otherwise associated with, particles or aerosols (Hg_p). Through atmospheric processes, some elemental mercury is converted to oxidized mercury, Hg(II). Both Hg(II) and Hg_p are subject to relatively rapid wet and dry deposition. Some of this deposition falls on the land, and some falls on the ocean. In the ocean and other waterbodies, Hg(II) enters into a cycle involving Hg^o, Hg_p and methylated forms of mercury, CH_3Hg. Oceanic Hg^o tends to leave the ocean and enter the atmosphere (evasion). The mixed surface layer of the ocean, which extends to approximately 100 meters in depth, contains an estimated 10,800 tons (a ton is equal to 10^3 kg) of mercury. Much of this mercury is anthropogenic; in pre-industrial times the surface layer of the ocean is estimated to have contained approximately 1/3 of what it contains today. Likewise, pre-industrial mercury deposition to the land and the oceans is estimated to have been approximately one-third of the current quantity.

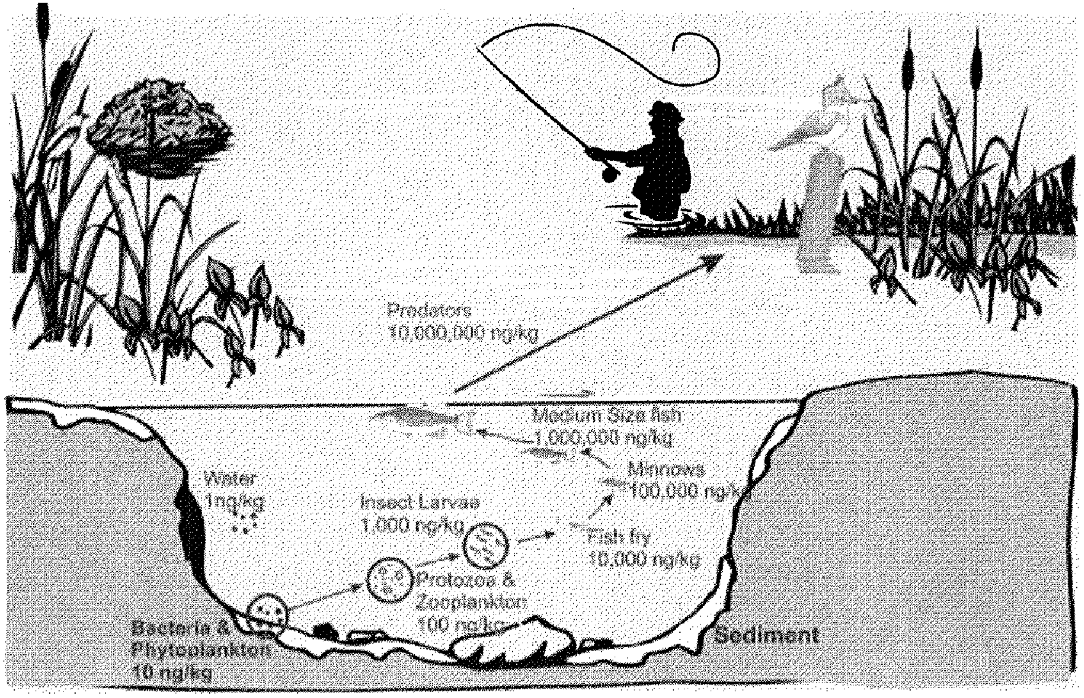
Mercury present in the bottom sediment of aquatic environments can be methylated by certain bacteria to form methylmercury. Methylmercury is far more bioavailable and more toxic than other forms of mercury. Furthermore, methylmercury is highly retained in organisms, and therefore, becomes biomagnified through aquatic food chains. Predatory fish commonly have methylmercury up to a million times greater than the concentration of mercury in the waters in which they live. As a result, higher level predators, including predatory fish as well as those organisms that feed on fish (such as birds, aquatic mammals, and humans), may accumulate methylmercury at levels sufficient to cause toxic effects. The biomagnification process is shown conceptually in Figure 1.2.

Toxicity from methylmercury can take the form of neurological and developmental effects in humans, as well as reproductive and other effects in wildlife. Although adults are susceptible to methylmercury toxicity, the fetus (particularly the developing brain) is considered the most sensitive target, and mercury control is predicated on protecting this sensitive target.

Although methylmercury is the form of mercury that poses the most widespread hazard to public health and ecology, elemental mercury can pose a health hazard under certain circumstances, including spills and intentional use. Exposure to elemental mercury may be an important health concern for certain population groups. Exposure to other forms of inorganic mercury can also be a concern at certain levels in drinking water.

The main pathway of exposure to methylmercury that is of concern is through the mother's consumption of fish. Although some mercury is released to the environment from natural processes (for example, volcanic activity and erosion), most mercury in our environment is anthropogenic, from many different sources - local, regional and global.

Figure 1.2
Typical Pattern of Mercury Biomagnification



Establishment of Task Force

Recognizing the ubiquity of mercury in the environment, including relatively high concentrations in some species of fish in New Jersey lakes, the high toxicity of methylmercury, and the fact that many people consume fish, Commissioner Robert C. Shinn, Jr., of the New Jersey Department of Environmental Protection (NJDEP) formed this Mercury Task Force by Administrative Order 1998-08 on March 9, 1998.

The Task Force was charged to:

1) Review the current science on
    a) impacts of mercury pollution on public health and ecosystems
    b) mercury deposition, transport, and exposure pathways.
2) Inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution.
3) Utilizing available information, quantify mercury pollution's impact on New Jersey's ecosystems, public health, and tourism and recreational industries.
4) Review New Jersey's existing mercury pollution policies.
5) Develop a mercury pollution reduction plan for the State of New Jersey, including:
    a) Recommend mercury emission controls and standards for in-state sources, including: coal-fired generators; hazardous waste incinerators; sludge

incinerators; hospital waste incinerators; and for other sources deemed necessary by the task force. In recommending controls and standards, the task force will explore renewable energy and alternative fuels to mercury-containing fuels now in use, and review innovative and low cost emission reduction strategies available in various industrial sectors.

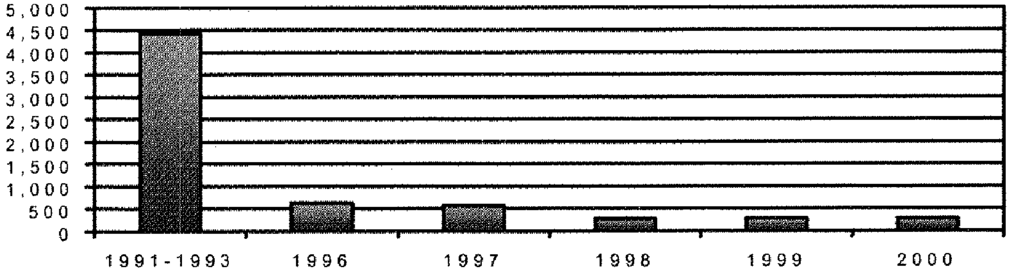
b) Provide timely interim recommendations, as feasible, prior to completion of the task force's overall mission, to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls and standards and the relationship of energy deregulation to mercury pollution.

The first New Jersey Mercury Task Force began in 1992 and focused attention on mercury emissions from Municipal Solid Waste Incinerators (MSWIs). Its report resulted in NJDEP regulations which set an air emissions standard of 28 micrograms per dry standard cubic meter (μg/dscm) by the year 2000 (with an interim standard of 65 μg/dscm to be met by 1995), or 80 percent removal of mercury emissions. Through an aggressive program of source reduction (removing mercury from products, especially batteries), source separation (removing mercury-containing products from the waste stream), and emission controls, all five of New Jersey's MSWIs were able to meet the new standard, thereby greatly reducing in-state air emissions of mercury. Since the first Mercury Task Force, medical waste incinerator emissions were also significantly reduced with source separation and mercury-free purchasing practices. The first Task Force, and additional study by NJDEP scientists, also broke significant new ground in the assessment of the public health risk from methylmercury from fish consumption. This work was subsequently confirmed by assessments conducted by the U.S. Environmental Protection Agency.

In 1996, the first year after mercury controls were required on New Jersey municipal solid waste incinerators, greater than 85% mercury reductions was demonstrated. By 1998, overall mercury reduction improved to about 94%, primarily with increased carbon injection control efficiency. (See Figure 1.3)

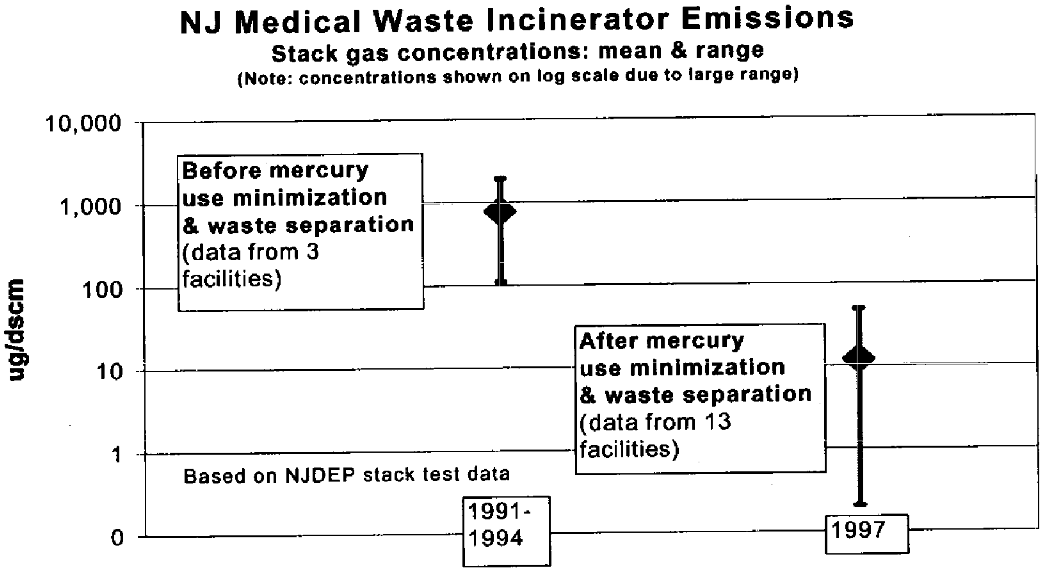
Mercury emissions from New Jersey medical waste incinerators were reduced from a median of about 900 μg/dscm to about 10 μg/dscm, which is about an 98% reduction. This was achieved primarily by mercury-free product purchasing by hospitals and also by mercury waste separation prior to incineration. (See Figure 1.4)

Figure 1.3.
Annual Mercury Emissions from NJ Municipal Solid Waste Incinerators



Follow-up studies, particularly of mercury levels in freshwater fish, revealed that mercury pollution was more pervasive in New Jersey, as well as other states, than previously known. Moreover, studies of fish consumption by the general public and pregnant women in New Jersey revealed a significant minority of women whose fish consumption resulted in an exposure to methylmercury which presented a potential risk to their developing fetuses.

Figure 1.4



The current Task Force began its deliberations in March 1998. It was composed of representatives of state agencies, recreational and commercial fishing interests, industrial and institutional stakeholders, environmental groups, and academic groups. Its main work was accomplished by two subcommittees, the Impacts Subcommittee (see Volume II) and the Sources Subcommittee (see Volume III). All meetings were open to the public. Many additional stakeholders, mercury experts, and representatives of various NJDEP programs were invited to make presentations to the Task Force and to participate in discussions.

The Administrative Order charged the Task Force with developing interim recommendations in addition to the final recommendations. Five interim recommendations were made and can be found in Appendix V of this volume. The interim recommendations concerned: 1) strengthening the environmental component of Assembly Bill A-10 on energy restructuring; 2) endorsing the New England Governors' resolution on the virtual elimination of mercury; 3) adding an amendment to the Pollution Prevention rules; 4) strengthening the environmental component of Assembly Bill A-10 and the support of the Task Force for mercury to be explicitly on the list of substances for which disclosure will be required; and 5) supporting the New England Governors' resolution regarding retirement and stockpile management of mercury.

The Task Force gathered available information on the behavior of mercury in the environment and its impacts, its sources and control strategies, and also developed recommendations. Key recommendations are presented in this volume, as is a summary of the major findings of the Task Force. Additional recommendations are provided in Volumes 2 and 3.

Goals, Milestones, and Key Recommendations

OVERALL GOALS

The Task Force advocates an overall goal of the virtual elimination of anthropogenic uses and releases of mercury. This goal is consistent with the Mercury Action Plan adopted by the Conference of the New England Governors and Eastern Canadian Premiers. Removing mercury from products is an important part of this effort. The toxicity and persistence of mercury in the environment, and the statewide existence of high levels of mercury in fish, require that New Jersey move on as many fronts as possible to eliminate additional mercury discharges, emissions, and associated deposition. Regional, national, and global actions are also necessary because long-range transport of mercury results in widespread mercury pollution. Reduction of mercury releases will have collateral benefits, such as the reduction of other important environmental pollutants.

MILESTONES

The Task Force recommends that the State of New Jersey adopt a two-step milestone of a 75 percent reduction in air emissions below estimated 1990 levels by 2006 and an 85 percent reduction below 1990 levels by 2011. Looking forward, these milestones will require a greater than 50 percent reduction below estimated 2001 air emissions by 2006 and a greater than 65 percent below estimated 2001 levels by 2011. See Figures 1.5 and 1.6 below.

Figure 1.5

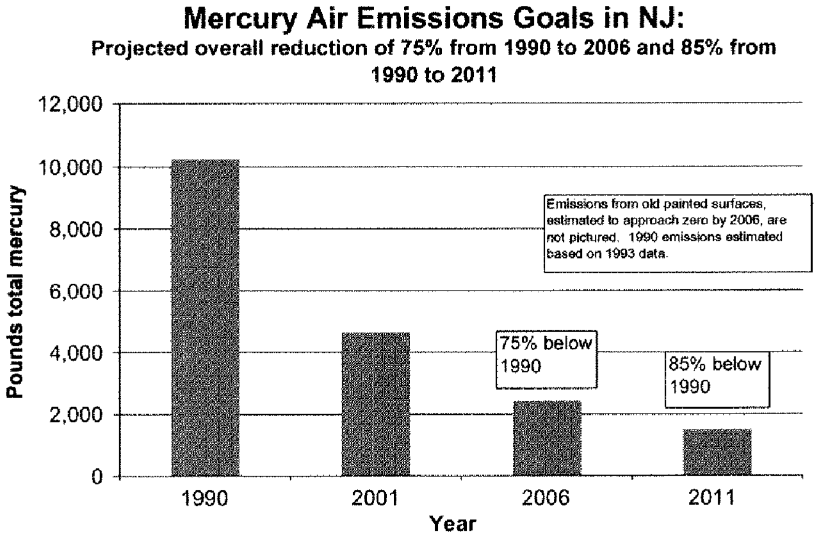
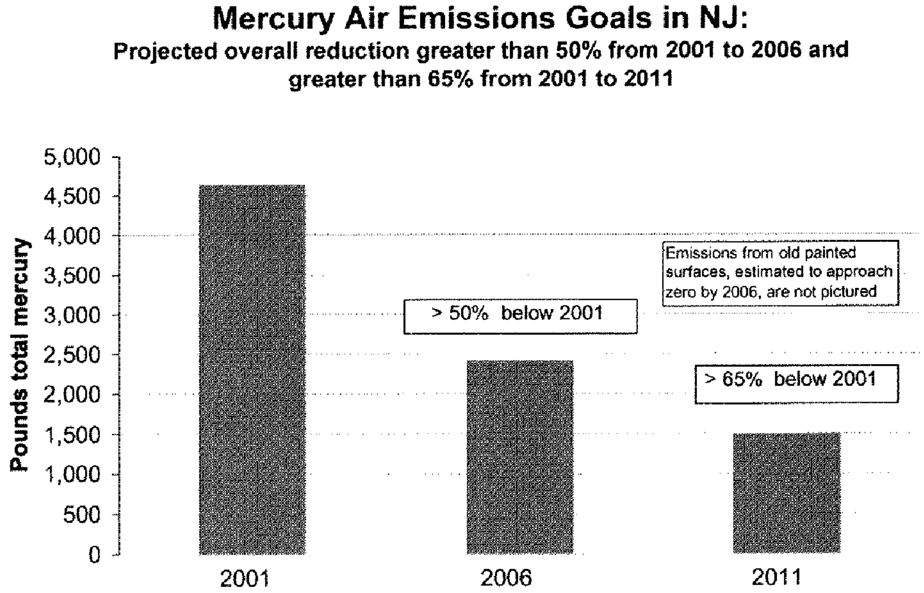


Figure 1.6



KEY RECOMMENDATIONS

The Task Force has found that numerous actions are needed to achieve the New Jersey air emissions reduction milestones. These milestones are based on the Task Force's assessment that realistic reduction of mercury from various sources can be achieved in New Jersey. Certain recommendations are considered key recommendations in that, if implemented, they could make large contributions to reductions in mercury uses or emissions and eventually lead to reductions of mercury in fish tissue. There is evidence from studies conducted in Florida that reducing air emissions can lead to reductions of mercury in fish tissue over a relatively short time period. Other key recommendations presented here are especially important in addressing critical knowledge gaps regarding mercury fate, transport, and exposure and in guiding public health outreach. The key recommendations are as follows (additional details and recommendations are provided in Volumes 2 and 3):

A. **Participate in and support regional, national, and global efforts to reduce mercury uses, releases, and exposures.** This is important to New Jersey because a significant portion of mercury in the State's environment originates from emissions elsewhere. Examples of efforts include the following: the Conference of the New England Governors' and Eastern Canadian Premiers, Northeast States for Consolidated Air Use Management (NESCAUM), Environmental Council of the States (ECOS) and U.S. Environmental Protection Agency (U.S. EPA) Mercury Action Plan.

B. **Remove mercury from products** and phase out sales of mercury-containing products for which there are reasonably available alternatives. In order to accomplish this, New Jersey should:
   1. Adopt legislation that reflects the provisions of the Mercury Education and Reduction Model Act prepared by the Northeast Waste Management Officials' Association (NEWMOA), as part of the New England Governors' Mercury Action Plan. This plan addresses mercury-containing products, such as thermometers, thermostats, switches (including those in motor vehicles and appliances), and fluorescent lights, and limits the sale of mercury to approved purposes.
   2. Develop effective outreach and education on the importance of removing mercury from products. County household hazardous waste programs should play a key role in this effort.
   3. Encourage phasing out the use of mercury-containing amalgams to the extent compatible with good dental practices, to further limit mercury releases to the environment.
   4. Use state purchasing and service contracts to reduce the purchase and use of products containing mercury, including motor vehicles containing mercury switches.
   5. Ensure that substitutes for mercury are not more hazardous than the mercury itself.
   6. Work with interstate organizations to assist in the development of federal legislation that minimizes the use of mercury in products.

C. **Reduce emissions of mercury from the production of electricity** consumed in New Jersey, including electricity generated by out-of-state sources. To accomplish this, New Jersey should:

   1. Promote energy efficiency with measures consistent with the NJDEP Greenhouse Gas Sustainability Action Plan.
   2. Promote the increased use of electric power from certified green sources including renewable sources and sources with low or zero mercury emissions.
   3. Require environmental information disclosure of mercury emissions per kilowatt-hour from all providers selling electricity in New Jersey consistent with The New Jersey Electric Discount and Energy Competition Act (EDECA) of 1999 (N.J.S.A. 48: 38).

D. **Significantly reduce air emissions from coal combustion**. To accomplish this, New Jersey should:

   1. Urge the U.S. EPA to rapidly develop and implement stringent limits on mercury emissions from coal combustion. These standards should include output-based performance limits (mg/MW-hr), which are applied to individual coal-fired power plants, in addition to national caps (tons/year), which are applied to the electric generation source category as a whole.
   2. Adopt State standards if, by December 2003, U.S. EPA does not proceed to promulgate and implement effective mercury limits on coal combustion.
   3. Work with interstate organizations to assist in the development of federal multi-pollutant legislation that limits mercury emissions as well as other pollutants.

E. **Significantly reduce air emissions from iron and steel and other secondary smelting industries.** To accomplish this, New Jersey should:

   1. Urge the federal government to require the rapid phase out of the use of mercury-containing products in new vehicles. Following the lead of other states, New Jersey should consider banning the sale of vehicles containing mercury products.
   2. Implement a phased strategy to reduce mercury contamination of scrap through elimination and separation measures. If, after a 3-year period, the source reduction measures do not achieve emission reduction goals, require the installation of air pollution control.
   3. Ensure that measures to reduce mercury contamination of scrap are developed through a cooperative process involving government agencies and affected industries, including automobile manufacturers, automobile recyclers, and those who crush, shred, or otherwise process scrap metal.
   4. Determine the amount of mercury emitted from secondary aluminum smelting and require reduction if significant.

F. **Ensure the minimization of mercury emissions from other sources**. To accomplish this, New Jersey should:

   1. **Medical Waste Incinerators** - Adopt the NEGA/ECP (New England Governors and Eastern Canadian Premiers) recommended emission limit for medical waste incinerators. All New Jersey medical waste incinerators already have achieved this level with pollution prevention measures. Adopting a limit will prevent backsliding and help provide an example to other jurisdictions.

2. **Sewage Sludge Incinerators -** Revise the State's sewage sludge mercury rules to reflect a phased reduction in mercury levels to meet the Task Force's goal of 2 ppm within 10 years. Consider a stack emission standard such as the New England Governors Association's recommended emission standard for sludge incineration facilities as an alternative to the final sludge concentration goal.
3. **Municipal Solid Waste Incinerators –** Consider revising the State's air pollution control regulation governing Municipal Solid Waste Incinerator (MSWI) emissions to include U.S. EPA's higher efficiency requirement for post-combustion emissions controls, thereby changing New Jersey's alternative limit based on efficiency from 80% to 85%. The 28µg/dscm primary requirement would remain the same.
4. **Other** - Develop methods to appropriately regulate and otherwise manage the disposal of discarded mercury-containing products, including fluorescent bulbs, dental amalgam waste, thermostats and switches.

G. **Expand and institutionalize routine monitoring for mercury in fish** from New Jersey waters through State-level programs.

H. **Actively encourage the federal government to initiate and maintain comprehensive monitoring and surveillance for mercury in commercial fish** and to require that information regarding the mercury content of fish be made readily available. If the federal government does not initiate nation-wide evaluation of commercial fish, New Jersey should, with other states in the region, monitor mercury in commercial fish.

I. **Expand and periodically evaluate the effectiveness of current outreach, advisories and education efforts** to reduce exposures to mercury of sensitive populations, subsistence fishermen, and others who consume large quantities of fish. To accomplish this, New Jersey should:

1. Increase public awareness of the public health concerns regarding mercury in fish and the need to reduce the emissions and releases to the State's waterbodies.
2. Expand outreach on fish advisories, particularly for sensitive populations, subsistence fishers, and others who consume large quantities of fish.

J. **Reduce exposures from cultural uses of mercury**. To accomplish this, New Jersey should:

1. Complete research and evaluate available data on cultural uses and associated exposures.
2. Provide outreach and education materials to communities and health professionals.
3. Develop and implement appropriate legislation and regulations that limit the sale of elemental mercury, except for medical and other approved uses, reflecting the NEWMOA model legislation.

K. **Develop comprehensive mercury budgets for New Jersey watersheds that include inputs from air deposition, in order to develop appropriate total maximum daily loads (TMDLs).** To do this, New Jersey should:

1. Utilize the most recent information developed through the U.S. EPA's pilot mercury TMDL development projects.

2. Determine the relative mercury contribution to aquatic systems from various sources and from repositories in environmental media.

L. **Maintain and enhance a long-term air deposition monitoring system** that incorporates state-of-the-art detection limits and speciation to document temporal and spatial trends in mercury deposition.

M. **Address critical information gaps** concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, New Jersey should:

1. Upgrade procedures used in all monitoring programs to include state-of-the-art analytical methods to provide lower detection limits for mercury and mercury speciation.
2. Employ a state-level, long-range dispersion model for mercury using the up-to-date emissions inventories including the inventory developed by the Mercury Task Force.
3. Encourage federal agencies to expand existing national research on the ecological effects of mercury, particularly on piscivorous (fish-eating) fish, birds and mammals (particularly marine mammals).
4. Identify demographic characteristics and exposure patterns of population groups in New Jersey that consume large quantities of fish.
5. Consider establishing the mercury-contaminated sites in the Berry's Creek area as an Environmental Research Park, patterned on the National Environmental Research Park system. This could serve as a resource for studies and monitoring of the complex processes governing the fate and transport of mercury in both the terrestrial and estuarine environment.

N. **Support the development of effective methods of retiring and sequestering mercury** so that the chances of the eventual release of mercury to the environment are minimized.

O. **Develop improved environmental indicators** of the impact of mercury on New Jersey's environment. To accomplish this, New Jersey should:

1. Expand and maintain a statewide ground water monitoring program for mercury.
2. Develop and apply indicators of trends of mercury in environmental media, including air deposition, mercury concentrations in surface water, mercury entry into aquatic food chains, mercury levels in fish tissue, mercury levels in human tissue in the New Jersey population, and mercury levels in feathers of piscivorous birds nesting in New Jersey.

P. **To provide for the implementation of the recommendations in this report**, New Jersey should:

1. Form within the New Jersey government, a multi-agency committee, including the Department of Environmental Protection, Department of Health and Senior Services, Department of Transportation and the Board of Public Utilities, to advocate the implementation of the recommendations and to report periodically to the Legislature and the Commissioner of the NJDEP on progress toward achieving the mercury milestones.

2. Establish the position of an environmental mercury coordinator in the NJDEP as has been done in other states.

Q. **Reduce mercury levels in fish and other biota.** Mercury concentrations in freshwater and estuarine fish in New Jersey should, at a minimum, be in compliance with the EPA's recent Surface Water Criterion of 0.3 μg/g methylmercury in tissue. This guidance value, aimed at protecting human health, may not be adequate to protect the health of the fish. Therefore mercury levels in surface water and fish tissue should achieve levels protective of aquatic life and of wildlife (the criterion for which is currently under development). Assessing this criterion requires the use of improved analytic methodologies that lower detection levels by at least an order of magnitude.

In addition to these key recommendations, the Task Force made five interim recommendations, which are included as an appendix at the end of this volume.

Summary of Findings

FORMS OF MERCURY IN THE ENVIRONMENT

Mercury occurs in a variety of forms which are all toxic to varying degrees. The forms or 'species' of mercury (Hg) are usually classified into the broad categories of organic and inorganic. They have different physical, chemical and toxicological properties. There are several forms of organic Hg. However, monomethylmercury, usually referred to simply as methylmercury (MeHg), is the most widespread organic form of Hg in the environment, and the form which poses the greatest threat to human and ecological health. It is formed by bacteria in aquatic environments from inorganic mercury. Another organic mercury compound, dimethylmercury plays an important role in the biogeochemical cycle of mercury in the ocean, but is too short lived from an exposure perspective.

The inorganic forms of mercury include elemental mercury (Hg^0) and also the salts of mercury. Of the mercuric compounds, mercuric sulfide (HgS) is the most stable of the common inorganic species and is essentially insoluble in water. It thus tends to function as a long-term sink for environmental Hg in soils, sediments and minerals. Those inorganic mercury compounds that are moderately soluble in water can contaminate surface and groundwater, and are largely responsible for the elevated levels of Hg in some private wells in areas of southern New Jersey.

Exposure to elemental mercury can occur from dental amalgams, in certain workplaces, in health care facilities, and occasionally in homes. Droplets of mercury are attractive to humans, and children have been known to bring mercury home to play with. The cultural practice of Santeria can also result in household exposures to elemental mercury. Breakage of thermometers and spills from gas meters during their removal are infrequent, but important sources of mercury exposure. When such spills occur it is important that they be cleaned up quickly avoiding dispersion of the material. In ambient air, Hg^0 vapor in the atmosphere is subject to long range transport. Some fraction of atmospheric Hg^0 is eventually oxidized to Hg(II) through atmospheric processes. Once converted to the Hg (II) form, the Hg is subject to relatively rapid deposition, either by precipitation or as dry deposition. Air deposition constitutes a major source of mercury to New Jersey's environment.

OCCURRENCE OF MERCURY IN ENVIRONMENTAL MEDIA

Understanding exposure pathways is essential for estimating and reducing risk. A pathway begins at the source of the pollutant, continues through an environmental medium (air, water, soil, food), enters a receptor's body through inhalation, ingestion, or through the skin, reaches the blood stream, and is eventually distributed to the critical or target organ where it can exert its toxic effect.

Methylmercury

Fish consumption is the only significant pathway of environmental human exposure to MeHg. The potential exists for significant exposure particularly to young children and toddlers through soil ingestion if MeHg per se (or other forms of organic Hg) is discharged directly to the soil. MeHg in soil can also be a significant source of MeHg in aquatic systems. Little attempt has been made to identify MeHg in plants grown on Hg contaminated soil. To date, only trace levels of MeHg have been found in air. Few investigations of the presence of MeHg in drinking water have been undertaken. Data from wells with largely inorganic Hg contamination in New Jersey show only trace quantities of MeHg.

Inorganic Mercury

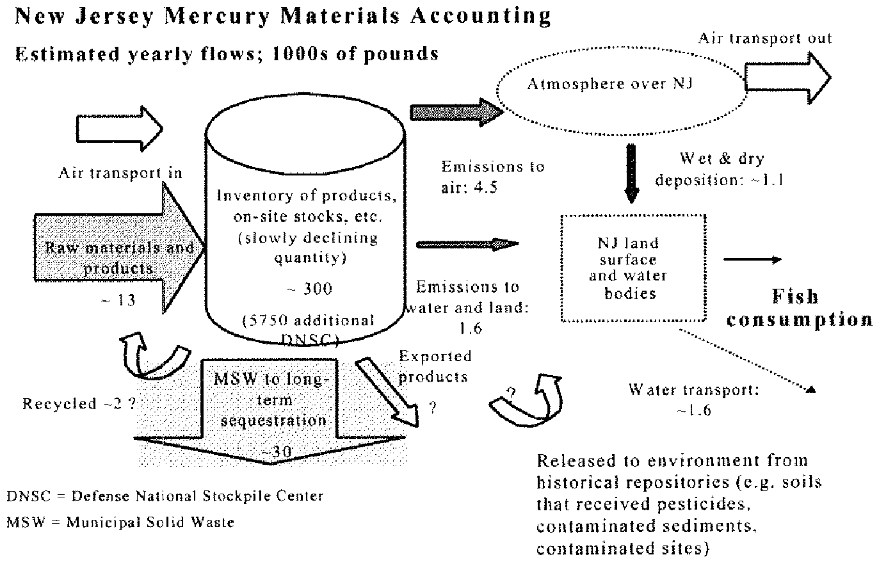
Although the diet contains trace amounts of inorganic Hg salts, they are not well absorbed, and do not generally constitute a significant route of exposure. Soil may contain elevated background levels of Hg salts, and soil may be contaminated with Hg salts from anthropogenic activity. Trace levels of inorganic Hg, both elemental Hg vapor and oxidized forms are found in ambient air. However, ambient levels of Hg found in ambient air do not constitute a significant route of direct exposure. Elemental Hg vapor can be present in indoor environments due to spills, or intentional application. Very little elemental Hg in indoor environments is required to pose a health hazard from inhalation. Inorganic Hg in drinking water has been observed in some locations particularly in shallow wells. While such contamination is largely due to Hg salts, some elemental Hg has been observed in such cases. Elemental Hg volatilized from water during showering may result in significant exposure under some circumstances.

SOURCES, FATE, AND TRANSPORT

Mercury has long been used in commerce in a variety of products and applications, and it is an inherent contaminant of fossil fuels. There is ample evidence that global mercury deposition rates and background atmospheric concentrations have increased significantly over the past 150 years. In one study, mercury accumulation rates in Great Lakes sediments were found to have increased by factors ranging from 50 to over 200 times from pre-industrial to modern times. Even in relatively remote areas, mercury accumulation rates appear to be 3 or more times higher now than before the Industrial Age. It is estimated that anthropogenic emissions are between 3600 and 4500 metric tons (8 to 10 million pounds) per year. The anthropogenic portion represents from 67% to greater than 75% of the yearly total global input, which also includes emissions from geologic sources and repositories of anthropogenic Hg in environmental media.

A materials accounting estimate for New Jersey has been developed. Figure 1.7 depicts yearly flows in thousands of pounds where estimates are possible. Flow quantities, represented by arrows in the figure, represent one year's flow. In this figure, mercury inputs to the State in the form of raw materials and products, and outputs in many forms, including air emissions, direct releases to water and land, and transport to disposal facilities are shown.

Figure 1.7



Also shown in the materials accounting figure are inputs to the State from wet and dry deposition from the atmosphere, which is the route by which it is believed most mercury that eventually becomes biologically available enters our environment. This quantity is a function of the amount of mercury present in the atmosphere over New Jersey, and of the factors that lead to the conversion of this mercury into forms that are incorporated into precipitation or which are susceptible to dry deposition. This quantity is influenced by both in-state emissions and mercury transported into the state from elsewhere.

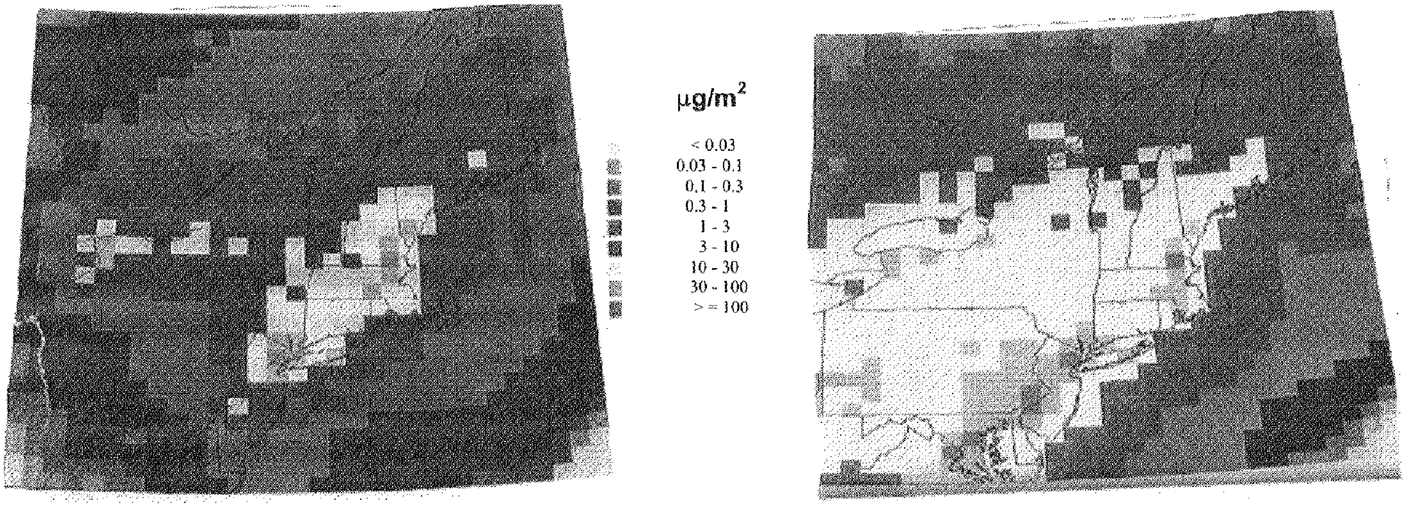
Also shown are arrows representing unknown or difficult to quantify fluxes of mercury. One such unknown flux is the release of mercury from historical repositories, which include the land surface and sediments and aquatic systems. Another flux that is difficult to characterize in a materials accounting context is the mercury in the atmosphere that flows across the State without depositing.

Figure 1.7 also provides the estimated inventory quantity. This includes mercury present in products and other items currently in use or storage, such as thermostats, thermometers, and dental amalgam. It is estimated that this inventory is slowly shrinking largely due to disposal of municipal solid waste (MSW) in landfills. The amount of Hg leaving this inventory is larger than the amount entering due to decreasing use of Hg in products.

The inventory of mercury contained in products and substances in use is augmented by 2615 metric tons of mercury stored at the Defense National Stockpile Center (DNSC) in Somerville, NJ, one of four national mercury storage sites. This mercury is stored in flasks in a secure, monitored warehouse. A federal environmental impact study is underway, due in Spring of 2002.

Deposition from the atmosphere is important in the overall cycle. Hg deposition in New Jersey can come from local, regional or global sources. Existing data do not permit a definitive determination of how much of the mercury emissions from New Jersey sources are deposited locally. Some reports and models do provide some insight on the relative local and non-local share of deposition, however. It has been estimated that perhaps one third of U.S. emissions to the air are deposited within the U.S., with the remainder joining the global atmospheric pool. It is also estimated that 50% of total mercury deposition may be accounted for by local or regional sources (see Figure 1.8 below, which shows estimated deposition from both in-region sources and from all U.S. sources). National mercury deposition data, coupled with additional data generated by the NJ Atmospheric Deposition Network, provide evidence that wet deposition rates of mercury are higher near population centers, providing further indication that a significant portion of the total deposition quantity results from relatively local sources. Areas of high rainfall that are also close to population centers, such as South Florida, show the highest deposition.

Figure 1.8
Estimated Total Mercury Deposition in the Northeast from In-Region Sources and from All U.S. Sources.



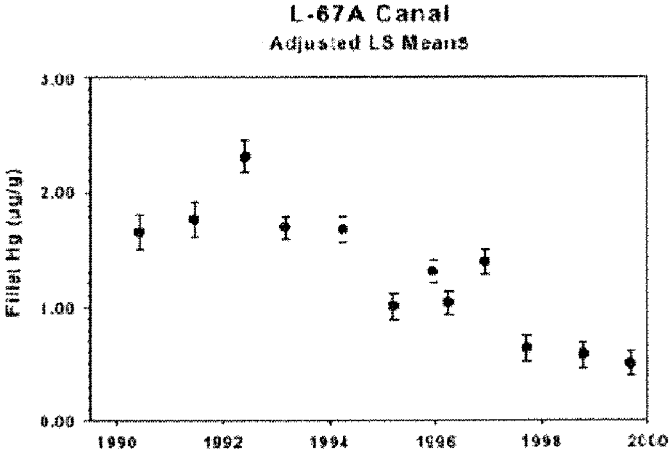
Hg deposition from in-region sources

Hg deposition from all U.S. sources

(Source: NESCAUM et al. Northeast States and Eastern Canadian Premiers Mercury Study - A Framework for Action. February 1998)

Recent research suggests that reductions of anthropogenic emissions of mercury will lead to significant reductions of Hg in aquatic species within a relatively short period of time. A Florida modeling study indicated that control of current mercury emissions could significantly alleviate the overall Everglades mercury problem within a decade or two and data on mercury levels in bass show a decline in the 1990's (Figure 1.9) following reduction of local emission. These data suggest that known emission reductions in sources such as waste incineration and painted surfaces taking place in the early- to mid-90s have led to relatively rapid declines in fish tissue concentrations. Other research suggests that, in the New York/New Jersey Harbor, if inputs of fresh mercury should cease, concentrations of mercury in fish would decline by 50% within approximately 20 years.

Figure 1.9
Changes in Mercury Concentration in Tissue of Largemouth Bass in a Florida Everglades Location in Conjunction with Reductions of Emissions of Mercury from Local Sources



Mercury in fillets of age-standardized largemouth bass in Everglades Canal L-67 (Lange et al., 2000). Adjusted least square means.

The Task Force's estimates of releases to the air, water, and land from New Jersey sources, based on data from the late 1990s and 2000, are depicted in Figures 1.10 and 1.11. In these figures, estimated uncertainties are shown with the lines extending to the left and to the right of the source bar, representing the range of values in which the real value could reasonably be expected to occur. These uncertainties are judgements reflecting the Task Force's confidence in the numbers. The sources of the data are also indicated. These include stack tests (direct measurements of air releases at specific times), mass balances (estimates based on some measurements, e.g. concentration of mercury in crude oil multiplied by total quantity refined in NJ), or other, usually more subjective, methods such as engineering judgement. Individual sources categories of air emissions span a range of over 900 pounds per year for New Jersey iron and steel manufacturing facilities to nearly zero for some New Jersey sources such as medical waste incineration and wood combustion. The four largest source categories, based on relatively certain estimates, are iron and steel manufacturing, coal combustion, products not elsewhere listed (including broken fluorescent bulbs), and solid waste incineration.

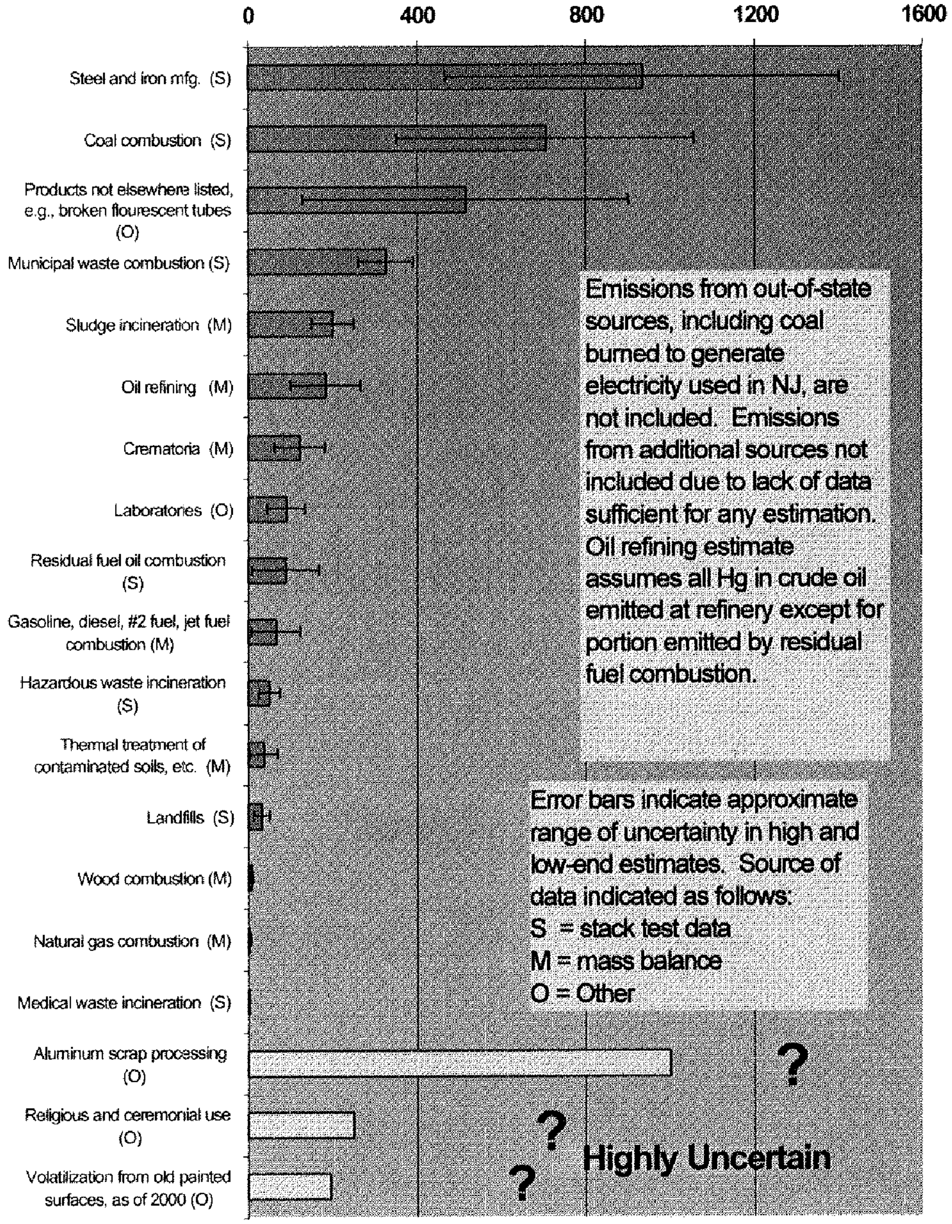


Figure 1.10

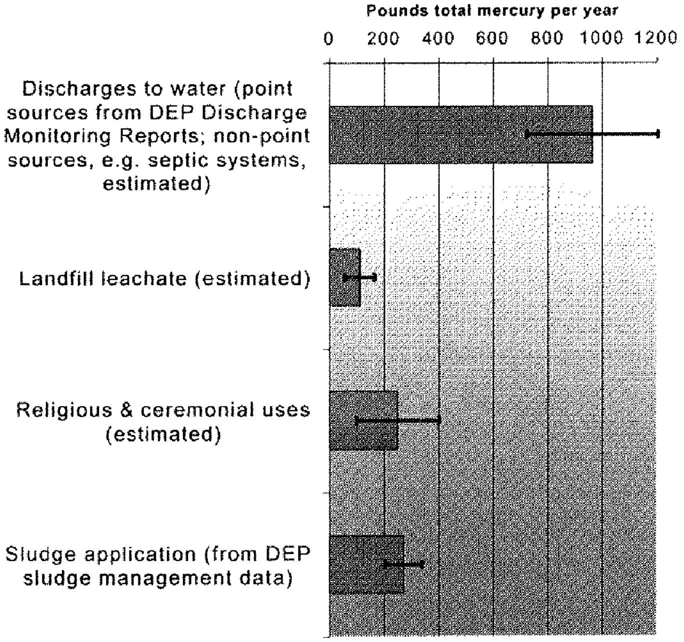
Estimated Mercury Emissions to Air; NJ Sources, lbs/yr

Based on most recent source-specific data; late 90s to 2001

Emissions from out-of-state sources, including coal burned to generate electricity used in NJ, are not included. Emissions from additional sources not included due to lack of data sufficient for any estimation. Oil refining estimate assumes all Hg in crude oil emitted at refinery except for portion emitted by residual fuel combustion.

Error bars indicate approximate range of uncertainty in high and low-end estimates. Source of data indicated as follows:
S = stack test data
M = mass balance
O = Other

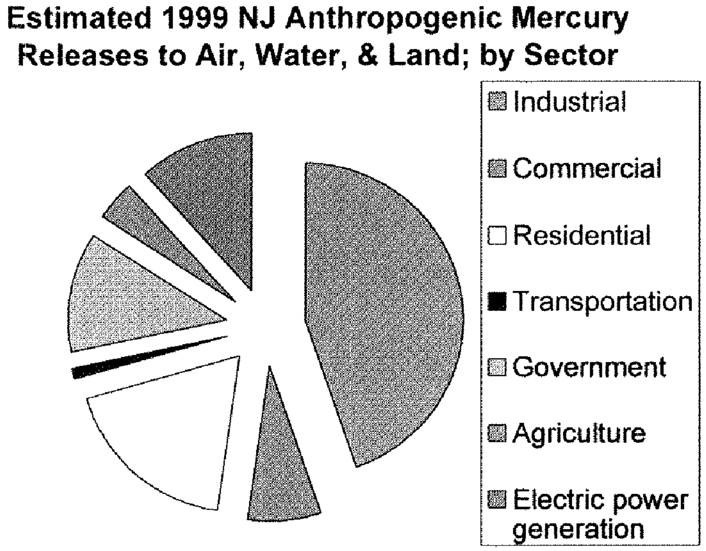
Figure 1.11



Estimated Anthropogenic Mercury Releases to Water Bodies and Land; NJ Sources
(Based on most recent data; 1997 through 1998)

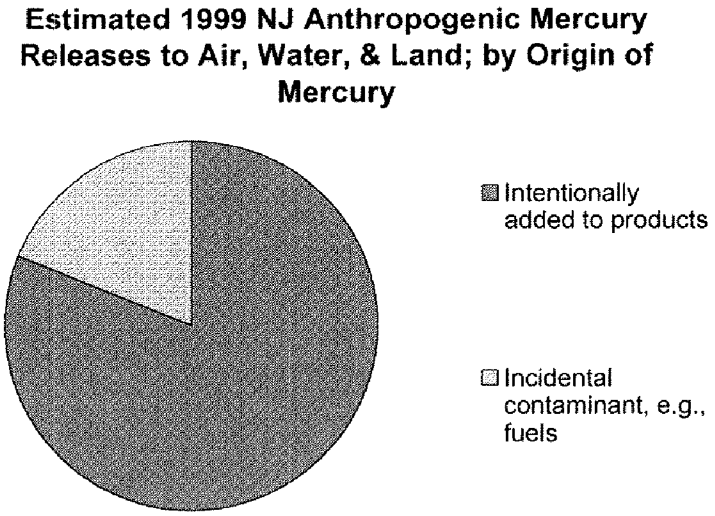
Releases can also be categorized by the sector from which the releases originate. This approach offers insight in developing reduction strategies, particularly those that involve outreach and communication. Source sectors can be characterized as residential (private dwellings), commercial (including retail stores, hospitals, schools and other institutions), industrial (manufacturing facilities), electric power generation, transportation, government (municipal solid waste management and public wastewater management), and agriculture. An apportionment of New Jersey mercury releases by sector is presented in Figure 1.12. The electric power sector can be further apportioned by the sectors using the power, such as industrial, commercial, residential, and government.

Figure 1.12



Releases can also be organized by the origin of the mercury. There are two broad categories of origin. In one case, mercury can be intentionally added to a product or used directly in an intentional manner. Alternatively, mercury can be present as an unwanted contaminant in a product. Release may occur during use, or through breakage or disposal. A review of the mercury releases noted in Figure 1.12 suggests that approximately 80% of the mercury released from New Jersey sources is mercury intentionally added to products. See Figure 1.13.

Figure 1.13



CHANGES IN SOURCE QUANTITIES OVER TIME

Reduction goals discussed previously can be broken down into components representing the various sources. These individual source components of the overall reduction goals are shown in figures 1.14 and 1.15 below. Note that reductions of emissions from municipal solid waste incineration and medical waste incineration resulted in large reductions of total NJ emissions during the period from 1990 to 2000. Between 2001 and 2011, the greatest portions of the projected overall reduction are reductions in emissions from iron and steel manufacturing facilities, non-ferrous and aluminum processing (approximate estimate) and from coal combustion.

Figure 1.14

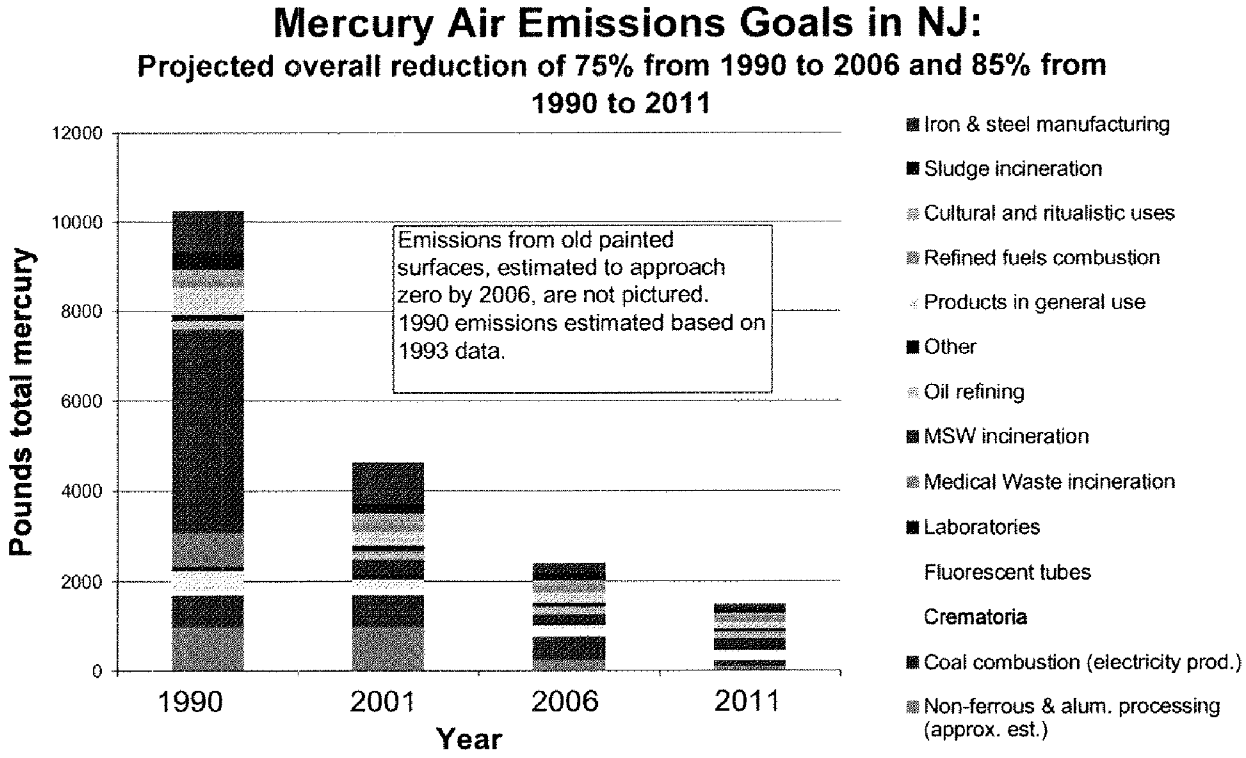
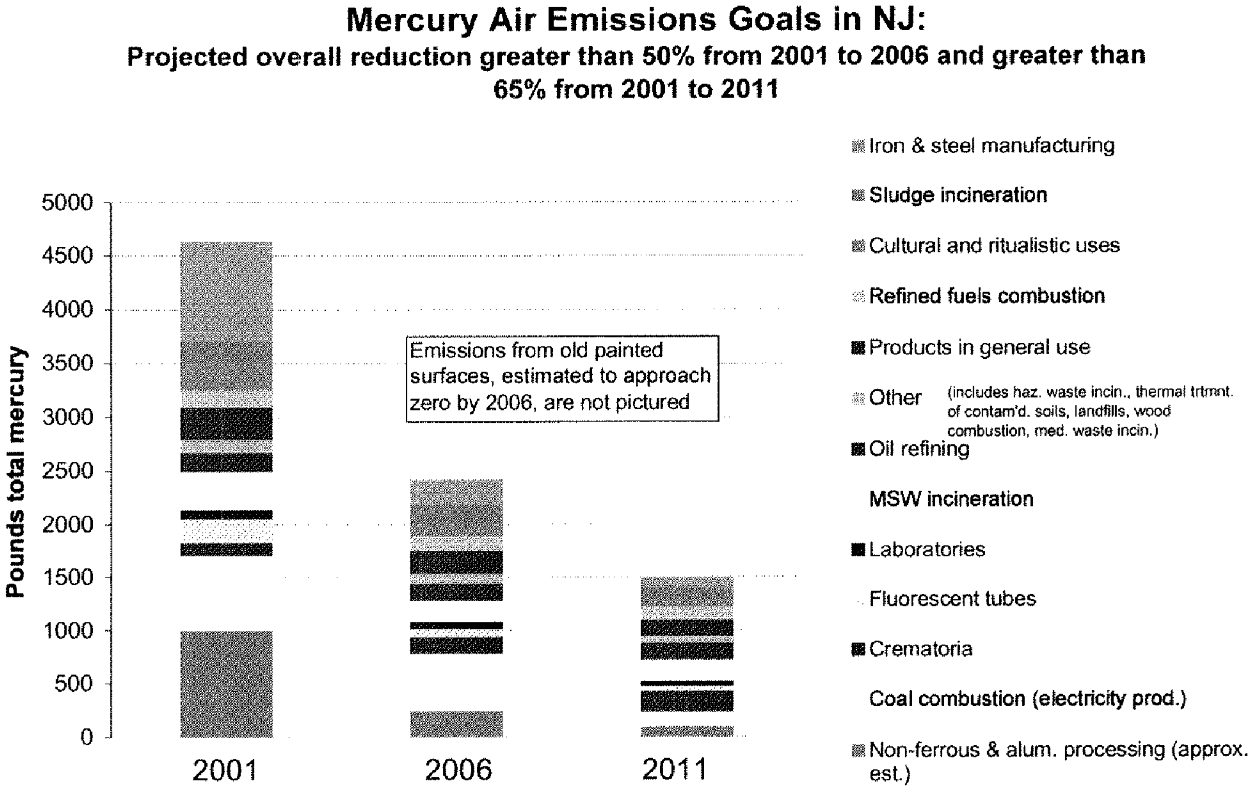


Figure 1.15



EXPOSURE PATHWAYS

Nationally, the most important source of exposure to mercury is the consumption of fish, although in certain areas of New Jersey, drinking and showering with water from private wells can be a significant source of mercury exposure. The extent of exposure from cultural uses of mercury is not known and such practices appear to be limited to specific communities. There is a long history of occupational exposure to mercury. Nationally, the most significant occupational exposures have ended, although limited exposure may continue in specific settings, most companies using or manufacturing mercurials have ceased these activities in the state. Dental amalgams and the pharmaceutical preservative Thimerosal may also be significant sources of exposure to individuals. The potential health implications of these latter exposures remain uncertain, and are largely beyond the scope of this Task Force.

Mercury Exposure from Commercial Fish

Based on data from the early 1970's, the average Hg concentration in muscle tissue in commercial fish in the U.S. intended for human consumption was 0.11 ppm, and the most commonly consumed species generally had levels in the 0.1-0.2 range. Tuna are generally in the range of 0.1-0.4 ppm. Higher trophic (predatory) level fish (e.g., Swordfish, Shark) reach 2 ppm. More recent data suggest that mercury levels in commercial fish may have declined over the past 20 years, perhaps reflecting reductions in industrial uses and releases of mercury, and/or changes in the size of fish harvested. Nonetheless, elevated levels of mercury, exceeding 1.0 ppm, are found in some species of commercial fish, such as tuna, swordfish and king mackeral. The lack of regular and systematic sampling of commercial fish is a serious impediment to assessing and communicating the risk to fish consumers.

Nationwide, it appears that nearly all adults and most children eat at least some fish. The average fish consumer eats 1-3 fish meals per week (including canned tuna), but a significant fraction of the population eats five or more meals per week. The consumption by women of childbearing age is generally comparable to or lower than that of the general population. The frequency of consumption appears to have increased significantly since the 1970's, although lack of comparability of survey methods makes precise comparisons to recent trends difficult. Tuna and shrimp account for about half of the total fish consumption.

Mercury Exposure From Non-Commercial Fish

Mercury (MeHg) has been shown to enter the aquatic food chain very rapidly, and is readily bioaccumulated to elevated levels in many recreational sport fish. Fish at the top of the food chain, which are typically gamefish species, can bioaccumulate methyl mercury to levels up to a million times greater than levels of mercury found in the surrounding water.

In 1984 and 1985, the U.S. Fish and Wildlife Service (USFWS) identified mercury concentrations in predatory fish species (e.g., trout, walleye, largemouth bass) that were at nearly twice the level in bottom dwelling species (e.g., carp, catfish and suckers). U.S. EPA's National Study of Chemical Residues in Fish (NSCRF) study found the mean mercury concentration in bottom feeding fish species to be generally lower than the concentrations found in top level predatory species. In addition, the study revealed that the majority of the elevated mercury concentrations were in fish collected from the northeastern states. A 1998 NESCAUM report on mercury concentrations in fish collected from northeastern states (including New Jersey) and eastern Canadian Provinces found that the top level sport fish species, such as walleye, chain pickerel, largemouth bass and smallmouth bass typically exhibited the highest mercury concentrations. Highest mercury concentrations were identified in a largemouth bass (8.94 ppm) and smallmouth bass (5.0 ppm).

The U.S. EPA's 2001 report, National Listing of Fish and Wildlife Advisories collected from 43 states provides a national mean mercury concentration for several predator and bottom feeding fish species. The national mean mercury concentrations for walleye, largemouth bass, smallmouth bass and brown trout were 0.52, 0.46, 0.34, and 0.14 ppm (wet weight) and 0.11, 0.11, and 0.09 ppm (wet weight) for carp, white sucker and channel catfish respectively.

Nationally, mercury accounts for the greatest number of fish consumption advisories issued by state agencies for recreational species of fish. U.S. EPA reports that almost 79 % of all the fish contaminant advisories issued were at least partly due to mercury contamination and that the number of states issuing mercury-related advisories has steadily risen. In 1993, a total of 899 mercury advisories had been issued from 27 states nationwide. In 2000, a total of 2,242 fish consumption advisories issued from 47 states due to elevated mercury concentration. The increase in mercury advisories is largely attributed to an increased awareness of mercury impacts in the aquatic environment and an increase in fish monitoring programs throughout the states.

HUMAN HEALTH EFFECTS AND TOXICOLOGY

The Task Force did not intend to undertake a new synthesis of the toxicology of mercury, but to provide a brief introduction and summary of the current state of knowledge. Significant uncertainties remain, and a full presentation of the available data and their accompanying uncertainties is beyond the scope of this report. More complete discussion and analysis can be found in several recent publications including:

- The National Research Council's Toxicological Effects of Methylmercury (NRC, 2000)
- The U.S.EPA's Mercury Report to Congress (U.S.EPA, 1997)
- The ATSDR's 1999 update of its Toxicological Profile for Mercury (ATSDR, 1999)
- The report of the National Institute of Environmental Health Sciences' Workshop on Scientific Issues Relevant to Assessment of Health Effects from Exposure to Methylmercury (NIEHS, 1998).

Methylmercury Neurodevelopmental Toxicity

It is clear that MeHg is a neurotoxin that can cause a range of developmental abnormalities in children exposed *in utero*. The critical question for assessing the impact of Hg on human health is whether, within the range of exposure associated with consumption of sport and commercial fish, there is a significant risk of adverse effects. There are now credible scientific data that indicate that at some currently encountered levels of fish consumption, significant risks can occur. These risks relate to subtle and population-based deficits in developmental performance, mostly within the range of "normal" performance. The current U.S. EPA Reference Dose (RfD) (essentially an estimate of the safe dose for the entire population including the most sensitive) for protection against such adverse effects (0.1 μg/kg/day) appears to be appropriate and protective. This value is based on an extensive scientific review by a committee of the National Academy of Sciences/National Research Council on which NJDEP was represented. This value is essentially identical to that recommended by the first New Jersey Mercury Task Force, and which forms the bases for New Jersey's current mercury fish advisories. Additional data from ongoing studies may further clarify this picture, but it is likely that uncertainties will remain for the foreseeable future.

Methylmercury Adult Toxicity

The former U.S.EPA RfD for MeHg (0.3μg/kg/day) was based on clinical neurological effects observed in adults. While this value has been superceded by the current RfD for developmental effects, it continues to be used to address the non-childbearing portion of the population. Current evidence suggests that more subtle neurological effects and/or non-neurological effects of MeHg may not be addressed by the "adult" RfD. Research, specifically addressing the potential for adverse effects at lower levels of exposure than those addressed by the "adult" RfD, are needed.

Inorganic Mercury

Salts of inorganic Hg primarily affect the kidney, but are not well absorbed by ingestion. Elemental mercury primarily affects the central nervous system, and is well absorbed by inhalation, but not by ingestion. Subtle neurological effects may occur with even low levels of exposure to elemental mercury making elemental mercury spills and intentional use of elemental mercury in residences potentially dangerous.

ECOLOGICAL EFFECTS OF MERCURY

Mercury compounds have been widely distributed in the environment. Due to the discharge and transport of mercury, organism exposure in aquatic and terrestrial ecosystems has resulted in the bioaccumulation of mercury. Mercury, primarily methylmercury, is quickly accumulated by aquatic biota, and methylmercury is the principal form of mercury that causes adverse effects. Biomagnification of mercury up the food chain is extensively documented, especially in aquatic systems: those predators at the top of the food chain accumulate the highest concentrations of mercury. Mercury accumulation by organisms has resulted in adverse effects ranging from death to sublethal effects. Mercury is a teratogen, and mutagen, and causes embryocidal, cytochemical, and histopathological effects. Ecosystem-level effects are not well characterized and additional study and data are needed to ascertain the impacts of mercury at this scale. Nonetheless, it is clear that fish-eating species, including birds, fish, and mammals, are especially at risk to the effects of mercury.

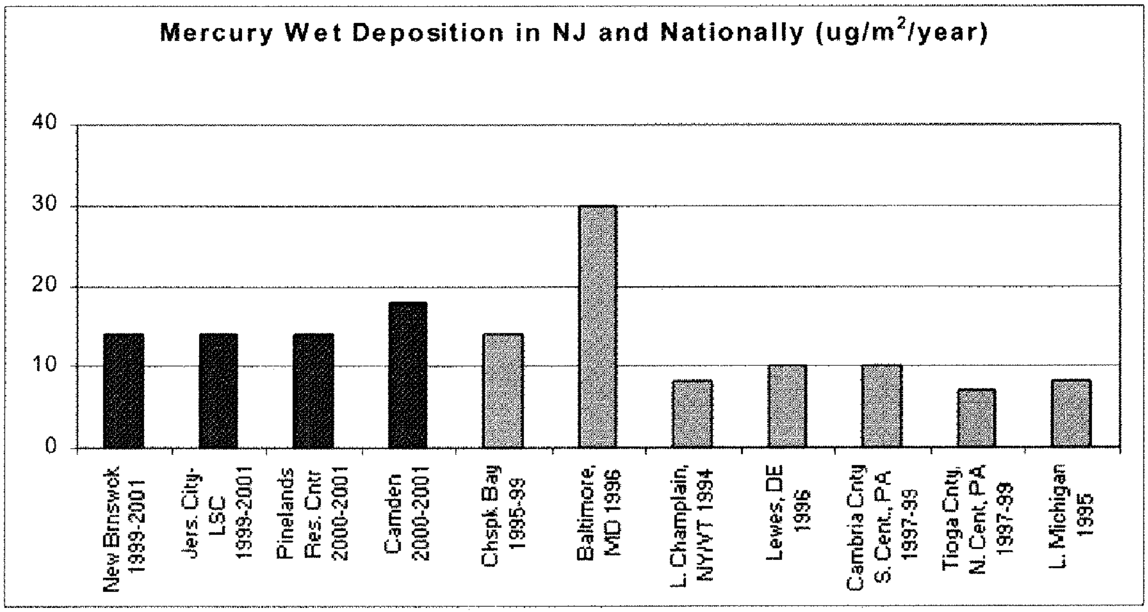
U.S. EPA developed a Water Quality Criterion (WQC) for mercury for the protection of wildlife (1.3 ng/L or parts per trillion) for surface waters of the Great Lakes. In addition, U.S. EPA has calculated a surface water wildlife criterion of 0.05 ng/L for methylmercury for protection of piscivorous mammals. These values are well below current Water Quality Criteria for the protection of aquatic life, and indicate that current surface water criteria may not adequately protect wildlife. Issuance of similar criteria should be considered for protection of wildlife nationally. In 2001, U.S. EPA issued its new surface water criteria of 0.3μg/g in fish tissue. The New Jersey Department of Environmental Protection is developing an implementation strategy for this new criteria.

OCCURRENCE AND IMPACT OF MERCURY IN NEW JERSEY'S ENVIRONMENTAL MEDIA

Mercury in Air

Mercury in ambient air in New Jersey does not pose a significant public health concern from inhalation. However, the deposition of airborne mercury onto surface water, and onto vegetation and soil, followed by transport to surface water, is the primary cause of mercury accumulation in aquatic biota. On the basis of preliminary data from the New Jersey Air Deposition Network, the deposition of mercury from the air to the surface from wet (precipitation) events is consistent with values reported elsewhere in the northeast, and is higher than the national average of 10 $\mu g/m^2$/year. See Figure 1.16 below.

Figure 1.16



Mercury in Groundwater in New Jersey

As a result of aggressive sampling of private wells undertaken by county governments in Atlantic, Ocean, and Gloucester Counties, mercury contamination in the Kirkwood- Cohansey aquifer in southern New Jersey has been identified and partially characterized. Depending on the county, between 1% and 13% of tested wells have been found with mercury concentrations exceeding the drinking water Maximum Contaminant Level of 2 µg/L (parts per billion). These results, however, are not based on random sampling and, therefore, do not permit conclusions about the overall occurrence of such exceedances. Based on studies conducted jointly by the NJDEP and the U.S. Geological Survey (USGS), it appears that this contamination results from human activity rather than natural sources. The great majority of the mercury is in the inorganic form as mercury salts. Approximately 10% of the mercury appears to be present as elemental mercury. The exposure from affected wells has been reduced by connection of residences to community water systems when feasible, or through installation of in-home point-of-entry treatment (POET) systems.

In homes receiving ground water contaminated with mercury, there may be volatilization during showering. The potential for exposure varies depending on elemental mercury concentration, shower temperature, nozzle type, ventilation, and shower duration. Under some possible scenarios, elemental mercury vapor can exceed the safe dose corresponding to the U.S. EPA Reference Concentration (RfC) for mercury in air. There are currently insufficient data related to the extent of contamination of well water by Hg to estimate the number of individuals or households potentially exposed to such levels of Hg°. When POET systems are installed or alternate water sources used, such exposures can be reduced or eliminated.

Mercury in Public (Community and Non-Community) Water Supplies in New Jersey

Mercury in public water systems has been monitored since the late 1970s. Over 4,000 public water system samples have been analyzed for mercury since 1993. In 2000, only three community systems and no noncommunity systems have had Maximum Contaminant Level (MCL) violations for mercury based on the MCL of 2 µg/L (2 part per billion). In general, mercury does not appear to be a problem for either community or non-community categories of public water supplies in New Jersey.

Table 1.1 Mercury in Public Water Supplies (based on data from the NJDEP Bureau of Safe Drinking Water, (1993 to 2000).

(Data from 1993 to 2000)	Community Water Systems	Noncommunity Water Systems
Total number of systems in NJ (as of end of 1997)	612	4100
# samples with Hg detections	383	185
# systems with Hg detections	169	133
# systems with Hg > 2 µg/L in at least one sample	11	13
Average of detected levels, µg/L	0.76*	1.0*
Median of detected levels, µg/L	0.40*	0.33
Range of detected levels, µg/L	0.1 – 8.0	0.04 - 10

*The great majority of samples had Hg levels that were below the detection limit. Therefore the true average values are well below the average for the detected values.

Mercury in Freshwater in New Jersey

There are no systematic data on mercury in New Jersey lakes. Data on mercury levels in New Jersey freshwater streams are somewhat difficult to interpret due to changes over time in the number of sampling locations, as well as changes in the detection limit. Nonetheless, it appears that the occurrence of elevated mercury in New Jersey streams has decreased since the 1990-1994 period. The current data, do not, however, allow an assessment of the potential for ecological impact relative to chronic effects on aquatic life. The number of stations exceeding the surface water criteria of 0.14 µg/L decreased from 20% of 79 (1990-1994) to 0% of 82 (1997-2000). The reason(s) for the decline remain to be studied.

Table 1.2 Percent of Monitoring Stations Exceeding Mercury Surface Water Quality Criteria

Sampling Period	Number of Stations Sampled	Percent of Stations Exceeding the Chronic Aquatic Life Surface Water Criterion (0.012 µg/L total Hg)	Percent of Stations Exceeding Human Health Surface Water Criterion (0.14 µg/L total Hg)	Percent of Stations Exceeding the Acute Aquatic Life Surface Water Criterion (2.1 µg/L dissolved Hg)
1990-1994	79	Not reported	20%	not reported
1/95-9/97	81	a	6%	0%
10/97-10/00 [b]	114 (82 stations evaluated with method detection limit = 0.1 µg/l)	a	0% [c]	0%

a. Samples were analyzed as total recoverable Hg and the method detection limit was 0.1 µg/l. Therefore, the chronic aquatic life criterion could not be evaluated.
b. The method detection limit for the sampling period was 0.1 µg/L.
c. Based on 82 stations sampled 1998-1999 with a method detection limit of 0.1 µg/L.

Mercury in Estuarine and Marine Waters in New Jersey

In the Hudson-Raritan Estuary, the mercury levels in the water column were found to exceed (or nearly exceed) the ambient surface water quality criterion of 0.44 µg/L. Recent sampling has shown that while mercury did not exceed the water quality criterion in Raritan Bay, the mercury water quality criterion was exceeded in the Raritan River, Newark Bay, the Hackensack and Passaic Rivers. Mercury levels were 15-35 times higher than the water quality criterion in the Passaic River. In the Delaware Estuary, the total loading of mercury is approximately one order of magnitude lower than some other toxic substances (e.g., silver, chromium, copper, lead, zinc, and polycyclic aromatic hydrocarbons).

Mercury in Freshwater Sediments in New Jersey

Compared to surface and ground water, the database on mercury in sediments is very sparse. Based on limited data, mercury levels in lake and stream sediments in some locations in New

Jersey are within the range of North American background of 0.04-0.24 µg/g (ppm). However, at some locations where specific mercury discharges have occurred, mercury levels in sediment greatly exceed background. Additional assessments are needed of historic and current levels of mercury loadings to the sediments/soils on a statewide basis with a comparison to regional and local sources of mercury loadings.

Table 1.3 Total mercury concentration in stream sediments from the New Jersey Ambient Stream Monitoring Network.

	1990-1997	1998
Average	0.042 µg/g (ppm)	0.034 µg (ppm)
Median	0.02 µg/g	0.018 µg/g
Range	0.01-1.0 µg/g	<0.01-0.35 µg/g
No. of samples	168	22
No. of sites	73	22
Detection limit	0.01 µg/g	0.01 µg/g

Mercury in Marine and Estuarine Sediments in New Jersey

Elevated levels of mercury are found throughout the sediments of the Hudson-Raritan Estuary and in locations in the Delaware Estuary. In addition, there are well-documented sources of site-specific mercury contamination in estuaries including Berry's Creek and Pierson's Creek. Mercury in water, sediments, and biota has been identified as a chemical of concern in these estuaries and the NY-NJ Harbor Estuary Program (HEP) is conducting extensive monitoring as part of the Toxics Source Reduction Plans in NY and NJ to address this problem. At least 75% of the NY-NJ Harbor sediments exceeded the lower range of the concentration corresponding to a threshold for effects on biota (ER-L), and many exceeded the estimated mid-range concentration for the effects threshold (ER-M) as well.

Mercury in Soil in New Jersey

It appears that background soil concentrations of mercury in New Jersey are generally low, with levels in urban areas higher than those in suburban or rural areas. Based on a study conducted by NJDEP (Fields, et. al. 1993), mercury levels in surface soils in New Jersey ranged from <0.01 to 0.3 mg/kg except for urban soils and golf courses, where mercury level reached a maximum of 7.7 mg/kg. Median values were below 5 mg/kg except for the golf courses, where the median mercury level was 5 mg/kg. This may reflect historical use of mercury-containing pesticides. Although comparisons are difficult, background mercury levels in NJ soil appear to be roughly comparable to background levels measured in other states.

IMPACT OF MERCURY ON NEW JERSEY ECOSYSTEMS

Impacts of Mercury on Specific Sites in New Jersey

New Jersey contains several major mercury contaminated sites. These include Berry's Creek, Pierson's Creek, Du Pont Chemicals-Pompton Lakes Works, and the Passaic River Study Area.

These sites resulted from the improper disposal of large quantities of mercury used in on-site industrial processes. Mercury has persisted at these sites for decades and thus has posed the potential for long-term impact on the surrounding ecosystems. In general, however, additional study on the impact of the mercury contamination on biota is needed at these sites and at adjacent locations.

Mercury Occurrence and Levels in New Jersey Fish

Freshwater Fish: Mercury is a widespread and persistent contaminant in freshwater fish collected throughout the state. Concentrations exceeding 1.0 ppm have been found in higher trophic level fish, particularly Largemouth Bass and Chain Pickerel, in about 40% of the tested waterbodies. Some lakes in urbanized areas of the state which are subject to local mercury pollution had fish with elevated mercury levels, but some lakes in other areas with no local sources of mercury, such as the Pine Barrens, also had elevated levels. Mercury concentrations in lower trophic level fish are also elevated and are commonly in the range of 0.2 to 0.5 ppm. Thus, many tested water bodies exceed the recent surface water criterion value of 0.3 ppm in fish tissue promulgated by U.S. EPA (January 2001). Waters impacted by industrial or municipal discharge, poorly buffered waters with low pH (e.g. many of the lakes in the Pine Barrens), and newly created lakes, tend to have fish with elevated mercury levels.

Saltwater Fish: Fishing is a major recreational and economic activity in the estuarine, coastal and offshore waters of New Jersey. There are an estimated 1.2 million anglers who take about 4.5 million saltwater fishing trips per year, at a value of $1.2 billion. Data on mercury levels in saltwater in New Jersey are limited and mainly reflect estuarine rather than marine species. Based on the currently available data, most species have moderately elevated mercury concentrations averaging less than 0.25 ppm. Striped Bass and Tautog, however, may have mercury concentrations in the range of 0.5 to greater than 1.0 ppm.

Table 1.4 Distribution of Mercury Concentrations in Largemouth Bass and Chain Pickerel in New Jersey Waterbodies Sampled in 1992-94 & 1996-97 (ANSP, 1994a, 1999)

Average Mercury Concentration for each Species	**Percent of Sampled Waterbodies** **Largemouth Bass**		**Chain Pickerel**	
	1992-94*	**1996-97***	**1992-94***	**1996-97***
<0.07 ppm	0 %	0 %	0 %	0 %
0.08 - 0.18 ppm	16.0 %	20.0 %	6.0 %	25.0 %
0.19 - 0.54 ppm	56.0 %	45.5 %	53.0 %	31.5 %
>0.54 ppm	28.0 %	34.5 %	41.0 %	43.7 %

*1992-94 Data (55 Waterbodies Sampled), 1996-97 (30 Waterbodies Sampled)

Impacts of Mercury on New Jersey Fish

There are two basic approaches that can be taken to assess the impact of mercury in New Jersey waters on the fish in those waters. One approach can be referred to as a direct approach. This involves making observations of fish health, survival, and performance as a function of their mercury exposure. The other approach can be referred to as an indirect approach. This involves comparing measured concentrations of mercury in water or in fish tissue to toxicity criteria for fish that were derived specifically for those media. This is a predictive or indirect approach.

Direct Assessment of Risk to New Jersey: There are very few data on the effects of mercury on New Jersey fish. Studies on Killifish from mercury contaminated estuarine/marine waters have demonstrated significant effects on many aspects of biology, behavior and viability, while a study of androgen levels in Largemouth Bass also showed the potential for significant reproductive impairment. Much more information is needed to draw general conclusions regarding the impact of mercury on fish health and reproductive capacity. These findings, however, raise concerns, and point out the need for research to examine the impact of mercury on the overall viability of fish in impacted NJ waterbodies.

Indirect Assessment of Risk to NJ Fish: Relatively low levels of Hg or MeHg can have chronic toxic effects on fish species. There are limited data for New Jersey waters. However, these data indicate the potential for chronic effects to fish in some waters of the State due to mercury. This potential is reflected in the exceedance of water quality criteria for chronic effects in both freshwater and saltwater fish. In particular, the NY-NJ Harbor area has exhibited mercury water concentrations above water quality criteria for effects on fish. Monitoring using more sensitive (i.e., lower detection limit) methods is needed to assess the levels of mercury in surface waters.

Impacts of Mercury on New Jersey Birds

Mercury levels in tissues, feathers, and eggs of several populations of New Jersey and New York Bight birds are close to or above levels anticipated to impair behavior, reproduction, growth and survival. Mercury was associated with developmental defects in Common Terns in the 1970's and high mercury levels are considered one of the stressors causing the decline of Common Loons. Mercury in the fish diet of Bald Eagles and Osprey appears to be elevated in the Delaware Bay region and may be a contributing factor to their potential lack of recovery in these regions.

Mercury in Other New Jersey Biota

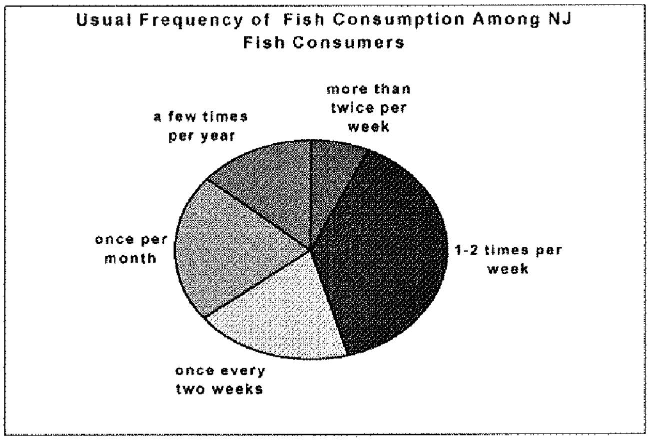
Very limited data on mercury exposure in plants and animals, other than birds and fish, are available. The data suggest that those mammalian species that are omnivorous, as opposed to herbivorous have elevated body burdens of mercury; however, data on carnivorous species in New Jersey are lacking. However, in the Everglades, some Panther deaths have been attributed to mercury poisoning. For reptiles, elevated levels are associated with the consumption of aquatic biota (fish and invertebrates). Information for evaluating the ecological risk implications of these isolated observations is lacking, and more information on mercury in these animals and in various plant species is needed.

IMPACT OF MERCURY ON PUBLIC HEALTH IN NEW JERSEY

Methylmercury Exposure from Fish Consumption in New Jersey

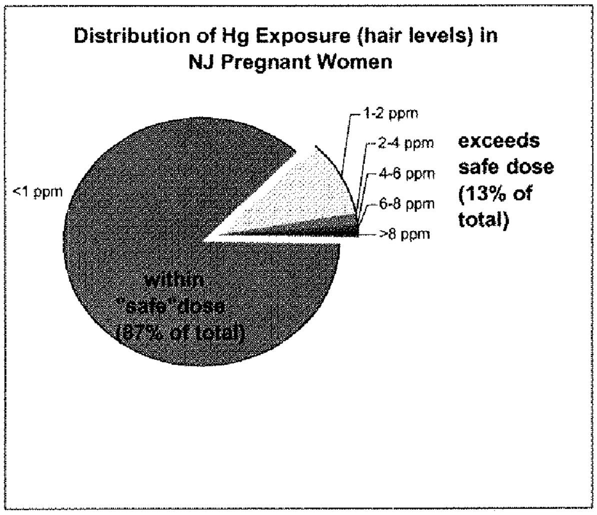
A very high proportion of the adult New Jersey population eats at least some fish. The mean fish consumption rate for those who eat some fish is estimated to be 50 g/day for all adults and 41 g/day for women of childbearing age. However, the top 5% of fish consumers eat fish at about three times this mean rate. These rates appear to be considerably greater than national consumption estimates derived largely in the 1970's and 1980's. This discrepancy may reflect a general increase in fish consumption over the last 10-20 years. The estimated mean daily MeHg dose for fish consumers is 0.08 μg/kg/day for all adults and 0.09 μg/kg/day for women of childbearing age. However, 5% of fish consumers are estimated to have MeHg exposures 3 times the mean dose, due to higher consumption rates. The distribution of MeHg exposures in New Jersey may be 1.5-3 times that estimated for U.S. fish consumers nationally.

Figure 1.17 Reported Usual Consumption of Fish Among 1,000 New Jersey Survey Respondents Who Reported At Least Some Fish Consumption in 1995.



The great majority of pregnant women in New Jersey appear to have low levels of exposure to Hg in general and to MeHg in particular. However, a small, but significant fraction of the pregnant population does have elevated exposures to MeHg from fish consumption. In general, African-Americans appear to have lower mercury levels than whites, and people with some college education appear to have lower mercury levels than those who did not complete high school. No data are available on mercury levels in people in NJ who regularly consume large amounts of fish.

Figure 1.18 Distribution of Total Hg in Hair from the Sample of NJ Pregnant Women.



(Note: 1 ppm mercury in hair approximately corresponds to the U.S.EPA Reference Dose for MeHg. This is the level of exposure at which no significant adverse effect is expected over a lifetime of exposure even to the most sensitive groups in the population).

Assessment of Risk to New Jersey Fish Consumers

There is no definitive way to estimate the percentage of babies born in New Jersey which could potentially experience adverse effects or subtle impairment because of pre-natal mercury exposure. However, there are several benchmarks against which risk can be gauged, and there are two studies which permit estimates of methylmercury exposure in the NJ fish-consuming population. It appears that 10-20% of the pregnant population in NJ has exposures which exceed a clear no-effect level (i.e., the U.S.EPA Reference Dose for methylmercury), and that 1-3% have exposures at which adverse effects might be observed. In addition, it appears that 5% of the general adult fish-consuming population in NJ has exposures which exceed a clear no-effect level for methylmercury (i.e., the previous U.S. EPA Reference Dose for adult health effects). These observations indicate that while the great majority of NJ fish consumers are at low risk from MeHg exposure, a small fraction of the population may have a significant level of risk. These exposure levels are comparable to those recently reported in the CDC/ NHANES IV assessment. None of these studies have targeted high-end consumers, people who deliberately eat large quantities of fish, often with 10 or more fish meals per week. In New Jersey, some adults and children eat sufficient amounts of fish to develop clinical signs of methylmercury poisoning.

Fish Consumption Advisories and Outreach in New Jersey

The NJDEP and NJDHSS have made significant effects to inform the public about new and existing fish consumption advisories for mercury and other contaminants in fish. Since advisories alone do not reach or convince all fish-eaters, additional press briefings, press releases and communications through the media have been undertaken to further communicate the existence and purpose of fish consumption advisories to as wide a group of populations as possible. The main audience for most of this information is the pregnant population, women planning to be pregnant or with young children and the recreational anglers of the state. Bilingual brochures have been distributed to populations at risk, but many target populations speak neither English nor Spanish. Advisories are annually updated and are made available to fishing license agents for distribution to the angling public. In addition, warning signs are posted and maintained on affected waterways around the state. Reaching salt water anglers remains a problem since no fishing license is required, thereby removing one of the important information channels. Research studies continue to provide new approaches to communicating with the targeted populations and outreach programs provide a means of encouraging public involvement in the education and protection of the public from the exposure to toxic chemical contaminants. For commercial fish, limited national guidance or current information on mercury levels in commonly consumed species is available to assist consumers in making informed choices.

Fish consumption provides substantial health benefits. In order to avoid discouraging consumers from fish consumption in general, outreach information must be carefully structured and worded to distinguish between low mercury fish and high mercury fish and to encourage the increased consumption of the former, especially by high-risk individuals.

Residential Exposure to Methylmercury in New Jersey

In at least one location in Hoboken, New Jersey, residents in an apartment building created from a former mercury vapor lamp factory were exposed to significant levels of mercury which appear to have resulted in adverse health effects in those exposed at the highest levels. The families have been evacuated and the building was found permeated with mercury and has been condemned. It is important that former industrial sites being converted into residential units be fully inspected for the presence of hazards like mercury before renovations begin.

In homes receiving ground water contaminated with mercury, there may be volatilization of elemental mercury during showering or cooking. The potential for exposure varies depending on the fraction of the total mercury which is present as elemental mercury, total mercury concentration, water temperature, nozzle type, ventilation, and exposure duration. Under some exposure scenarios the safe dose corresponding to the U.S. EPA Reference Concentration (RfC) for elemental mercury would be exceeded. There are currently insufficient data relating to the extent of contamination of well water by mercury to estimate the number of individuals or households potentially exposed to such levels of elemental mercury.

INDICATORS OF INPUT, ACCUMULATION, AND IMPACT OF MERCURY ON NEW JERSEY'S ENVIRONMENT

Indicators provide a critical tool for assessing environmental quality and for evaluating trends in environmental quality. This is especially important in conditions of environmental change such as those which are anticipated to result from reductions in mercury emissions in New Jersey and nationally. New Jersey already has in place an extensive indicator program under its National Environmental Performance Partnership System (NEPPS) and Strategic Planning processes. Useful indicators of the impact of mercury on New Jersey's environment are achievable for air deposition, mercury concentration in surface water, mercury entry into aquatic food chains, mercury levels in fish tissue, mercury levels in human tissue in the New Jersey population, and mercury levels in feathers of piscivorous birds nesting in New Jersey. All of these indicators have the strong potential to reflect relatively short-term changes in the entry of mercury into and movements through the New Jersey environment at various levels of environmental organization, and so are useful in gauging the efficacy of ongoing management efforts. Except for air deposition data generated from the current New Jersey Air Deposition Network, these indicators need to be developed, and require appropriate analytical assessment and program investments.

THE IMPACT OF MERCURY ON TOURISM AND RECREATION IN NEW JERSEY

The Task Force found no clear evidence that the issuance of fish advisories or the rising public concern about mercury have had a major influence on freshwater or salt water fishing.

To provide information on the potential impact of mercury contamination and mercury advisories on tourism and recreation in New Jersey, the Task Force commissioned a survey of charter and party boat captains in New Jersey.

A minority of party and charter boat captains interviewed reported that advisories in general did hurt their business to a greater or lesser degree. The Boat Captain Survey was not able to evaluate the accuracy of these reports. Reporting that advisories affected business, however, was consistent mainly for those captains who fished for bluefish in the waters of the northern part of the state. It is notable that although bluefish have moderately elevated levels of mercury, there is no mercury-based advisory for bluefish. There are, however, PCB-based advisories for bluefish in the waters of northern New Jersey (i.e., the Harbor Estuary). Furthermore, captains who fished for species with more elevated levels of mercury and which have been highlighted in the press as posing a potential health hazard (i.e., shark, tuna), did not tend to identify advisories as affecting their business. Although this survey cannot rule out a small impact from fish consumption advisories in general on the recreational fishing industry in New Jersey, it seems unlikely that mercury-based advisories in particular have any major impact on the industry.

Volume II of the New Jersey Mercury Task Force Report contains greater detail on the exposure and impact of mercury in the environment. Volume III contains further information on the sources of mercury to New Jersey's environment.

APPENDICES

I. Administrative Order 1998-08 and Original Task Force Membership List

II. Mercury Task Force Participants

III. Mercury Task Force Subcommittee Members

IV. Mercury Task Force NJDEP Participants

V. Mercury Task Force Interim Recommendations
    A. November 14, 1998 letter from Dr. Michael Gochfeld to NJDEP Commissioner Shinn on recommendations to strengthen the environmental component of Bill A-10 on energy restructuring
    B. July 17, 1998 Task Force meeting where the New England Governors' resolution 23-2 regarding the virtual elimination of mercury was endorsed.
    C. December 11, 1998 letter from Dr. Michael Gochfeld to NJDEP Commissioner Shinn on recommendation for an amendment to the Pollution Prevention rules
    D. January 11, 1999 letter from Dr. Michael Gochfeld to Governor Whitman to strengthen the environmental component of Bill A-10 and the urging of the Task Force for mercury to be explicitly on the list of substances for which disclosure will be required
    E. July 6, 2001 letter from Dr. Michael Gochfeld to Commissioner Shinn recommending support of the New England Governors' resolution regarding retirement and stockpile management of mercury

VI. Presentations at Task Force Meetings

VII. Acronyms

APPENDIX I
Administrative Order 1998-08

State of New Jersey
Christine Todd Whitman, *Governor*
Department of Environmental Protection
Division of Science, Research and Technology
P.O. Box 409
Trenton, NJ 08625-0409
Robert C. Shinn, Jr., *Commissioner*

ADMINISTRATIVE ORDER 1998-08

I, Robert C. Shinn, Jr., Commissioner of the New Jersey Department of Environmental Protection, pursuant to the authority of N.J.S.A. 13: 1 B-3, hereby establish a task force to be known as the Mercury Pollution Task Force.

It is recognized that mercury contamination compromises public health and the health of the ecosystem. It is persistent, mobile, and subject to bio-magnification in food chains, factors which make environmental exposure to this contaminant a significant human health risk. In New Jersey, mercury contamination has resulted in the issuance of fish consumption health advisories across the state for certain freshwater fish. New Jersey's efforts to address issues related to mercury contamination are reflected in the state's National Environmental Performance Partnership Agreement; this task force adds to and builds upon that commitment.

The reduction of Mercury contamination should be an additional component to our efforts to reduce the transport of ozone and its precursors from out of state sources, and be a major part of our continuing efforts to meet the standards of the Clean Air Act.

For the foregoing reasons, I am directing the task force to undertake a thorough examination of Mercury transport and deposition issues and to develop a mercury pollution reduction plan for New Jersey. This examination should include an analysis of the potential sources of mercury devolution into the environment.

The mission of the task force is to develop a mercury pollution reduction plan for New Jersey. The Task Force is directed to complete the following tasks:

1. Review the current science on: a) impacts of mercury pollution on public health and ecosystems; and b) mercury deposition, transport, and exposure pathways.
2. Inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution.

New Jersey is an Equal Opportunity Employer

3. Utilizing available information, quantify mercury pollution's impact on New Jersey's ecosystems, public health, and tourism and recreation industries.
4. Review New Jersey's existing mercury pollution policies.
5. Develop a mercury pollution reduction plan for the State of New Jersey, including:
    A) Recommend mercury emission controls and standards for in-state sources, including: coal fired generators; hazardous waste incinerators; sludge incinerators; hospital waste incinerators; and for other sources deemed necessary by the task force. In recommending controls and standards, the task force will explore renewable energy and alternative fuels to mercury emitting fuels now in use, and review innovative and low cost emission reduction strategies available in various industrial sectors.
    B) Provide timely interim recommendations, as feasible, prior to completion of the task force's overall mission, to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls and standards and the relationship of energy deregulation to mercury pollution.

Within the NJDEP, mercury is addressed in a multi-media approach by nine separate divisions, resulting in an overall program of considerable expertise. Therefore, I am directing that the task force take full advantage of the resources and expertise that the department has brought to bear on this important issue.

The task force shall be comprised of the following representatives appointed by the Commissioner of the Department of Environmental Protection (except as otherwise noted) and who shall serve at the pleasure of the Commissioner, from the following areas:

New Jersey Department of Environmental Protection: 1
New Jersey Board of Public Utilities: 1 (appointed by the President of the BPU).
New Jersey Department of Health: 1 (appointed by the Commissioner of the DOH).
Recognized public interest groups: 4
Hospital waste incinerators: 1
Co-Generation power electric generators: 2
Sewerage sludge incinerators: 1
Refineries/refinery products: 1
Hazardous waste incinerators: 1

Date

3/9/98

Robert C. Shinn, Jr.

Coal fired electric generators: 3 (1 from each generator)
Fresh water fishing organization: 1
Saltwater fishing organization: 1
At large citizen members: 4

I direct that the Task Force be administered by the Department, and that the Division of Science and Research within the Office of Environmental Planning and Science and the Office of Air Quality Permitting within the Office of Environmental Regulation as well as other necessary department resources be made available to the mission as set forth herein.

The Task Force may provide timely interim recommendations as feasible, to the Office of Commissioner of the Department of Environmental Protection, prior to the completion of the task force's overall mission. The Task Force shall report its final findings and recommendations to the Commissioner within 12 months of the date of the organizational meeting of the task force, at which time the Task Force shall terminate.

The Task Force shall meet regularly as it may determine, and shall also meet at the call of the chairperson.

A majority of the membership of the Task Force shall constitute a quorum for the transaction of Task Force business. Action may be taken, including the issuance of any findings, recommendations or reports, (interim or final), at any meeting of the Task Force only by the affirmative vote of a majority of the full membership of the Task Force.

This ORDER shall take effect immediately and shall supercede Administrative Order 1997-14 enacted December 15, 1997.

ADMINISTRATIVE ORDER 1998-08
Original Mercury Pollution Task Force Membership

NJDEP Representative: Leslie McGeorge

DHSS Representative: Jim Blumenstock

BPU Representative: Brian Beam

Public Interest Group Representatives:
Dolores Phillips, Center for the Environment and Public Health Policy
Ashok Gupta, Natural Resources Defense Council
John Guinan, NJ Public Interest Research Group
Nevil Cohen, INFORM

Coal-fired Generators:
Eric Svenson, PSE&G
Dan Cunningham, Conectiv
Michael Jones, U.S. Generating

Independent Power Producers:
Steve Gabel, Gabel Associates for Independent Energy Producers of New Jersey

William Potter, Potter & Dixon

Hospital Waste Incinerators:
Chris LaBianco, NJ Hospital Association

Sewage Sludge Incinerators:
Robert Dixon, Gloucester County Utilities Authority

Refineries/Refinery Products:
Robert A. Morris, P.E., REM, The Coastal Corporation

Hazardous Waste Incinerators:
Keith Michels, Safety-Kleen (Bridgeport), Inc.

Freshwater Fishing Organization:
Tom Fote, NJ Sportsmens Federation/Jersey Coast Anglers Association

Saltwater Commercial Fishing Organization:
Captain Nelson Beideman, Blue Water Fisherman's Association

Public Members:

Michael Gochfeld, MD, Ph.D., EOHSI/UMDNJ, Task Force Chairman
Henry Cole, Ph.D., Henry S. Cole & Associates, Inc.
Robert Tucker, Ph.D., Director, Research Professor, Rutgers University
Valerie Thomas, Ph.D., Center for Energy and Environmental Studies, Princeton University

APPENDIX II
Mercury Task Force Participants

APPENDIX II
Mercury Task Force Participants

Mercury Task Force Members		
Original Administrative Order Members	**Official Replacements**	**Other Active Participants**
NJDEP Representative *Leslie McGeorge		William Baker, EPA Region 2, Air
DHSS Representative *Jim Blumenstock		Andy Bellina, EPA Region 2, RCRA
BPU Representative *Brian Beam		Eric Vowinkel, USGS
Public Interest Group Representatives *Dolores Phillips, Center for the Environment and Public Health Policy		Jerry Marcus, Two Bridges Sewerage Authority
Ashok Gupta, Natural Resources Defense Council		Priscilla Hayes, Rutgers University, NJ Solid Waste Policy Group
John Guinan, NJ Public Interest Research Group	Jasmine Vasvada, NJPIRG	
Nevil Cohen, INFORM	Susan Goodwin, Alicia Culver, *Janet Cox, INFORM	
Coal-fired Generators: Eric Svenson, PSEG	*Betty Jensen, PSEG (resigned)	
Dan Cunningham, Conectiv (resigned)		
Michael Jones, U.S. Generating		
Independent Power Producers: *Steve Gabel, Gabel Associates for Independent Energy Producers of New Jersey		Russ Like, Gabel Associates

Original Administrative Order Members	**Official Replacements**	**Other Active Participants**
William Potter, Potter & Dixon (resigned)		
Hospital Waste Incinerators: Chris LaBianco, NJ Hospital Association		
Sewage Sludge Incinerators: *Robert Dixon, Gloucester County Utilities Authority		
Refineries/Refinery Products: *Robert A. Morris, The Coastal Corporation (resigned)		
Hazardous Waste Incinerators: *Keith Michels, Safety-Kleen (Bridgeport), Inc.		
Freshwater Fishing Organization: *Tom Fote, NJ Sportsmens Federation/Jersey Coast Anglers Association		
Saltwater Commercial Fishing Organization: Captain Nelson Beideman, Blue Water Fisherman's Association		
*Michael Gochfeld, MD, Ph.D., EOHSI/UMDNJ, **Task Force Chairman**		
Henry Cole, Ph.D., Henry S. Cole & Associates, Inc.		

(resigned)

*Robert Tucker, Ph.D.,
Stoney Brook-Millstone
Watershed Association

*Valerie Thomas, Ph.D.,
Center for Energy and
Environmental Studies,
Princeton University

*** Participating members
within the past year.**

APPENDIX III

New Jersey Mercury Task Force
Subcommittee Members

Impacts Subcommittee
Dr. Michael Gochfeld, Co-Chair
Alan Stern, Co-chair

Nelson Beideman
James Blumenstock
Tom Fote
Leslie McGeorge
Robert Tucker
Eric Vowinkel

NJDEP:
Gary Buchanan
James DeNoble
Mary Downes-Gastrich
Joann Held
Mike McLinden
Eileen Murphy
Bruce Ruppel

Sources Subcommittee
Robert Morris, Co-chair
Mike Aucott, Co-chair

William Baker
Brian Beam
Andy Bellina
Henry Cole
Janet Cox
Dan Cunningham
Robert Dixon
Steve Gabel
John Guinan
Ashok Gupta
Priscilla Hayes
Betty Jensen
Michael Jones
Chris LaBianco
Russ Like

Jerry Marcus
Keith Michels
Dolores Phillips
William Potter
Eric Svenson
Valerie Thomas

NJDEP:
Sunila Agrawal
Tim Bartle
John Castner
Bob Confer
Randy England
Ken Frank
William O'Sullivan
Tony Pilawski
Sue Shannon
Tom Sherman
Mike Winka

APPENDIX IV
Mercury Task Force
NJDEP Participants

Division of Science, Research and Technology
Mike Aucott, Co-chair Sources Subcommittee
Alan Stern, Co-chair Impacts Subcommittee
Gary Buchanan
Mary Downes-Gastrich
Randy England
Eileen Murphy
Bruce Ruppel
Sue Shannon
Mike Winka

Air Quality Permitting
Sunila Agrawal
Joann Held
William O'Sullivan

Pollution Prevention
Mike McLinden

Division of Water Quality
Tony Pilawski

Site Remediation Program
Jim DeNoble

Division of Solid & Hazardous Waste
Tim Bartle
John Castner
Bob Confer
Ken Frank
Tom Sherman

APPENDIX V

Mercury Task Force Interim Recommendations

A. November 14, 1998 letter from Dr. Michael Gochfeld to NJDEP Commissioner Shinn on recommendations to strengthen the environmental component of Bill A-10 on energy restructuring.

B. July 17, 1998 Task Force Meeting. The Mercury Task Force generally endorsed resolution 23-2 recommendations of the New England Governors and Eastern Canadian Premiers Mercury Action Plan, which includes the virtual elimination of the discharge of anthropogenic mercury.

C. December 11, 1998 letter from Dr. Michael Gochfeld to NJDEP Commissioner Shinn on recommendation for an amendment to the Pollution Prevention rules. This interim recommendation requested that the Department lower its Community Right-to-Know through put reporting threshold for mercury from 10,000 lbs./yr. Lowering the reporting threshold to 100 lbs./yr. would have provided the Department with more refined estimates regarding mercury usage and environmental releases. The Department began moving forward with the Task Force recommendation, however, EPA proposed its Persistent Bioaccumulative Toxic (PBT) substance rule in January 1999 and adopted an even lower 10 lbs./yr. reporting threshold for mercury later that year. The federal TRI amendments were automatically adopted by reference by the New Jersey Community Right To Know and Pollution Prevention Programs. Covered New Jersey facilities are now required to submit annual mercury throughout and release data if they use mercury in excess of 10 lb./yr.

D. January 11, 1999 letter from Dr. Michael Gochfeld to Governor Whitman to strengthen the environmental component of Bill A-10 and the support of the Task Force for mercury to be explicitly on the list of substances for which disclosure will be required

E. July 6, 2001 letter from Dr. Michael Gochfeld to Commissioner Shinn recommending support of the New England Governors' resolution regarding retirement and stockpile management of mercury

APPENDIX V
A. November 14, 1998 letter

E O H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES INSTITUTE

University of Medicine & Dentistry of New Jersey
Department of Environmental and Community Medicine
EOHSI Building---170 Frelinghuysen Road
Piscataway, NJ 08854
Phone 732-445-0123 X627 FAX 732-445-0130
email "gochfeld@eohsi.rutgers.edu"

To: Commissioner Robert C. Shinn, Jr.
New Jersey Department of Environmental Protection

From: Michael Gochfeld
Chair, Mercury Pollution Task Force

Date: November 14, 1998

Re: Recommendations to strengthen the environmental component of Bill A-10 on Energy Restructuring

- -

As you are aware, on March 9, 1998 an administrative order established the Mercury Pollution Task Force to provide recommendations to NJDEP on a mercury pollution reduction plan for New Jersey. The Task Force was directed to complete four tasks, one of them to provide timely interim recommendations (prior to completion of the task force's overall mission), to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls, and standards and the relationship of energy deregulation to mercury pollution.

On April 27, 1998, the first set of interim recommendations on energy restructuring was presented to you. At this time, I am pleased to forward to you additional recommendations of the Mercury Pollution Task Force on A-10, the bill for energy restructuring. These suggested modifications to the legislation are intended to reduce inputs of mercury and other air pollutants to New Jersey's environment, without interfering with the primary purpose of restructuring.

As you are also well aware, certain forms of electric generation have inherent environmental impacts associated with them. Nationally, mercury emissions from electric power plants, primarily coal-fired power plants, account for approximately one-third of the known total of anthropogenic air emissions of mercury from presently quantified stationary point sources (EPA, 1997, Mercury Study Report to Congress, Vol. II, EPA-452/R-97-004, Table 5-1). Electric power consumed by New Jersey's public, business, industry and government comes from a variety of in-state and out-of-state generating, some located hundreds of miles away and upwind of New Jersey's borders.

The Mercury Pollution Task Force believes that as the New Jersey Legislature is considering legislation to restructure the electric utility industry to provide full retail choice, the Administration and the Legislature need to ensure that New Jersey's air quality is not degraded, that reduction of emissions of mercury and other pollutants is encouraged, and appropriate market incentives are established to stimulate energy efficiency and the development of clean and mercury-free renewable electric generation.

The Mercury Pollution Task Force has specific consensus recommendations at this time for the Administration and Legislature to consider incorporating in Assembly Bill A-10.

These involve the insertion of Section 38 a. (3) (environmental disclosure):

> "Mercury emissions shall be added to this supplier disclosure in the shortest possible time, not to exceed 'eighteen months of the start of full retail choice- Within [twelve] 12 months of the enactment of this legislation, the Board in consultation with the NJDEP shall determine the availability of publicly reported data from electric power generators to US. EPA and other state and federal agencies concerning their emissions of mercury from electric power generators in North America. Within 18 months of the enactment of this legislation but no sooner than the Board's determination of the availability of publicly reported data on mercury emissions from electric power generators, the Board, in consultation with the NJDEP, shall require an electric power supplier or basic generation service provider, to include mercury emissions among the pollutants to be reported to the consumers in the manner specified in 38 a. (2). In the event that such data on mercury emissions from electric power generators are not publicly available, the Board in consultation with NJDEP shall establish default mercury emission values to be used by electric power suppliers or basic generation service providers in calculating the mercury emissions associated with the energy they generate or purchase".

The Task Force very much hopes that you will be able to encourage the legislature to incorporate these changes.

We expect to have additional comments and suggestions on this matter.

I should add that there was strong sentiment expressed about reducing the delay in disclosure to the shortest possible time frame.

On behalf of the task force, I am available to discuss any questions or concerns. I hope that you will be able to join us at our January or February meeting.

APPENDIX V
B. NGECP Resolution
July 17, 1998

State of New Jersey
Department of Environmental Protection

Christine Todd Whitman
Governor

Robert C. Shinn, Jr.
Commissioner

MEMORANDUM

TO: Robert C. Shinn, Jr., Commissioner

FROM: Leslie McGeorge, Director, DSR
Bill O'Sullivan, Administrator, AQP

SUBJ'ECT: Northeast Governors/Eastern Canadian Premiers Mercury Resolution and Action Plan (June 7-9, 1998)

DATE: July 27, 1998

Attached you will find copies of:
Resolution 23-2 (Resolution Concerning Mercury and Its Impact on the Environment)
as signed during the June 7-9, 1998 Northeast Governors/Eastern Canadian Premiers Conference. This Resolution has an Action Plan (also enclosed). You may recall that New Jersey and New York (through invitation) have assisted with the development of this Resolution and Action Plan.

We anticipate that the Director of the New England Governor's Conference will be sending a letter to Governor Whitman (and New York's Governor Pataki) requesting support and possible endorsement of the resolution (Note: reference to collaborate with New Jersey on p.5 of the Mercury Action Plan). We have asked that you be notified in advance of such correspondence being sent to the Governor's office.

Copies of the mercury-related documents, along with a presentation on the Action Plan, were provided to members of NJDEP's Mercury Pollution Task Force at their June 19, 1998 meeting. They were urged to review the documents to ensure that New Jersey's proposed plan is informed by this regional resolution and plan. At the July 17, 1998 meeting, they discussed a general endorsement of the regional approach articulated in the Mercury Resolution (23-2) and Action Plan. We recommend that you or Governor Whitman also generally endorse the mercury resolution and plan, pointing out that New Jersey is somewhat more stringent for Municipal Solid Waste Incineration (all units covered sooner), and that we are supportive of the use of the New Jersey 28 ug/m^3

mercury limit in their strategy. We would be happy to discuss the mercury resolution further with you at your convenience.

c: Bob Tudor, Assistant Commissioner, Office of Environmental Planning and Science
Gary Sondermeyer, Assistant Commissioner, Environmental Regulation
Randy England, DSR
Joann Held, AQP

APPENDIX V
C. December 11, 1998 letter

E O H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES INSTITUTE

681 Frelinghuysen Road P.O. Box 1 179 w Piscataway, N.J. 08855-1179
(908) 932-0180 Fax (908) 932-0130

OCCUPATIONAL HEALTH DIVISION

December 11, 1998

Robert C. Shinn, Jr., Commissioner
New Jersey Department of Environmental Protection
Office of the Commissioner
P.O. Box 402
Trenton, NJ 08625-0402

Dear Commissioner Shinn:

The Mercury Pollution Task Force is charged with developing a mercury pollution reduction plan to lower the levels of mercury, a bioaccumulative contaminant, in New Jersey's environment. In order to develop this plan, the administrative order establishing the Mercury Pollution Task Force directs the task force to "inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution." The Task Force recognized its charge to inventory sources of mercury as well as the need for addressing additional sources of mercury, which are not being reported at the current threshold level. There are a number of mercury sources for which the Task Force has little or no information, so it is important to capture these users and potential sources of mercury releases to New Jersey's environment.

During the November 13, 1998 Mercury Pollution Task Force meeting, the Task Force made a motion and voted 10-3 in favor of the following interim recommendations for Pollution Prevention rules

> **"The Mercury Pollution Task Force recommends as an amendment to the Pollution Prevention rules to lower the throughput reporting threshold of mercury to 100 lbs., and if feasible, establish an environmental release reporting threshold of two lbs./year."**

BACKGROUND:

Throughput Reporting Threshold

The Mercury Pollution Task Force understands that New Jersey's Pollution Prevention and Right-To Know rules currently have a throughput reporting threshold of 10,000 lbs./year for covered TRI (Toxic Release Inventory) facilities for each covered substance. The Mercury Pollution Task Force recommendation calls for a 100 lbs./year throughput reporting threshold for mercury (or mercury compounds) when the annual quantity, which is manufactured, processed or otherwise used at the facility greater than or equal to 100 lbs./year.

Release Reporting

The Mercury Pollution Task Force would like the NJDEP to examine whether the NJDEP has the authority to establish an additional release reporting threshold for mercury. This release reporting would include all mercury releases to the air, water, on-site disposal, and off-site transfer, which are equal to or greater than 2 lb./year. The Department's Air Quality Permitting Program uses a release threshold of two lbs./ year as stated in N.J.A.C. 7:27-8, which sets out the reporting thresholds for HAPs (Hazardous Air Pollutants). The Task Force recognizes that this second part of the recommendation may not be feasibly addressed through Pollution Prevention rules.

ADDITIONAL MERCURY POLLUTION TASK FORCE REQUEST:

In order to gather information on industries outside of SIC codes currently covered by the Pollution Prevention program, the Mercury Pollution Task Force also requests that the NJDEP Office of Pollution Prevention and Permit Coordination provide information to the Task Force on possible reporting strategies for mercury users that are not currently captured through regulations.

Respectfully submitted,

Michael Gochfeld

Michael Gochfeld, MD, Ph.D.
Mercury Pollution Task Force Chair

APPENDIX V
D. January 11, 1999 letter

New Jersey is an Equal Opportunity Employer

E 0 H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES DIVISION
170 Frelinghuysen Road Piscataway, N.J. 08854
(732)445-0123 EXT.627 Fax: (732)445-01302
email: "gochfeld@eohsi.rutgers.edu"

OCCUPATIONAL HEALTH DIVISION

January 11, 1999

The Honorable Christine Todd Whitman
Governor
State House
Trenton, NJ 08625

Dear Governor Whitman:

As you are aware, last spring DFP Commissioner Robert Shinn issued an Administrative Order establishing a Mercury Task Force. It is my privilege to chair that Task Force and to work with a dedicated group of Task Force members from many different sectors, as well as the excellent NJDEP support staff from several divisions. It has truly been a learning experience for all of us.

One of our specific charges was to examine the possible impacts of the then nascent energy restructuring proposals on mercury pollution of New Jersey's environment. Since a substantial part of our mercury comes from regional sources west of us, changes in electricity generation potentially will have a significant impact on New Jersey's air quality. Commissioner Shinn expressed to me his commitment to working on a regional basis to protect environmental quality, and mercury pollution is a prime example of a regional pollutant subject to long distance transport.

The Task Force addressed restructuring with great interest, and it was especially gratifying to me, to have the representatives of the utility (PSEG) and of environmentalist groups (NRDC) work together in crafting proposed wording to incorporate environment safeguards into the legislation. The attached recommendations were forwarded to the Commissioner in November.

I realize that developing such a complex piece of legislation is no easy task, but would be particularly unfortunate if our state which has invested so heavily in improving its environment, should produce a restructuring system that does not adequately protect future air quality.

Since some of the Task Force's suggestions are not in the draft legislation voted out of Committee last week, the Task Force, at its regular meeting last Friday, voted that I forward to you the recommendations that we believe should be incorporated into the bill which we understand is in the process of being amended and finalized.

I am respectfully attaching the original recommendations. Specifically, the Task Force strongly urges that mercury---one of our most significant toxic pollutants---be explicitly added to the list of substances for which disclosure will be required.

Since a major environmental issue is the development of renewable energy sources, it would also be desirable to empower the NJDEP to take the lead in developing renewable energy, putting New Jersey where it should be, in the forefront of this important environmental and economic development.

On behalf of the Task Force, I hope you will undertake to strengthen the environmental protection components of the restructuring legislation. Thank you for your attention.

Respectfully submitted,

Michael Gochfeld, MD, Ph.D.
Task Force Chair

cc: Commissioner Robert Shinn
Deputy Commissioner Judy Jengo
Deputy Commissioner Mark Smith

Attached: November 14, 1998 Recommendations to Commissioner Shinn for strengthening the environmental component of Bill A-10 on Energy Restructuring

APPENDIX V
E. July 6, 2001 letter

EOHSI

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES DIVISION
170 Frelinghuysen Road Piscataway, N.J. 08854
(732)445-0123 EXT.627 Fax: (732)445-01302
email: "gochfeld@eohsi.rutgers.edu"

OCCUPATIONAL HEALTH DIVISION

July 6, 2001

Robert C. Shinn, Jr., Commissioner
New Jersey Department of Environmental Protection
401 East State Street
P.O. Box 402
Trenton, NJ 08625

Dear Commissioner Shinn:

As chair of New Jersey's Mercury Task Force, I am writing about action taken by the New England Governors/Eastern Canadian Premiers (NEG/ECP). Although New Jersey is not part of the New England Governors Conference, the State has been invited and continues to participate in the NEG/ECP Mercury Action Plan discussions. On April 20, 2001, the NEG/ECP signed a resolution regarding retirement and stockpile management of mercury (copy attached). The resolution requests the Department of Defense not to sell stockpiled mercury until the development of a comprehensive strategy to manage and ultimately retire stockpiles of mercury is completed.

When you created the Task Force by signing Administrative Order 1998-08, the Task Force was charged to inventory and assess current sources of mercury pollution, in addition to providing timely interim recommendations to the New Jersey Department of Environmental Protection. The Task Force has reviewed and endorsed this resolution, finding it pertinent to the mercury stored at the Department of Defense Depot in Somerville. Our interim recommendation is for you to support this resolution.

Please feel free to contact me for further information at 732-445-0123, extension 627 or email address Gochfeld@eohsi.rutgers.edu

Very truly yours,

Michael Gochfeld, M.D., Ph.D.
Chair, Mercury Task Force

Attachment: NEG/ECP Resolution

C: Leslie McGeorge, NJDEP Assistant Commissioner Environmental Planning & Science
Cathy Tormey, NJDEP Assistant Commissioner Compliance & Enforcement
Randy England, NJDEP Division of Science, Research & Technology
Sue Shannon, NJDEP Division of Science, Research & Technology

APPENDIX VI

Presentations at Mercury Task Force Meetings

March 27, 1998

Energy Deregulation and Mercury Implications

> NJDEP Plan on Energy Issues – John Elston, NJDEP - Air Quality Management (AQM)
>
> Proposed Resolution on Electric Utility Restructuring - Ashok Gupta, Natural Resources Defense Council

Draft of Mercury Emissions Inventory – Bill O'Sullivan, NJDEP Air Quality Permitting (AQP)

Mercury in Ground Water and Related Sources – Eileen Murphy, NJDEP Division of Science, Research & Technology (DSRT)

Mercury in Fish and Consumption Advisories – Bruce Ruppel, NJDEP-DSRT

April 17, 1998

Mercury in Fish – Bruce Ruppel, NJDEP-DSRT

Risk Assessment and Fish Advisories – Alan Stern, NJDEP-DSRT

Ecological Impacts of Mercury – NJDEP Division of Fish & Wildlife (DFW)

Source Information from NESCAUM (Northeast States for Coordinated Air Use Management) Report – Joann Held, NJDEP-AQP

Berry's Creek Update – Rick Gimello, NJDEP Site Remediation Program (SRP)

Right To Know Information – Randy England, NJDEP-DSRT

May 8, 1998

Industrial Right to Know Information – Randy England, NJDEP-DSRT

Relationship of Strategies/Emission Controls for Reduction of Mercury and Other Air Pollutants – Bill Baker, U.S. EPA and Bill O'Sullivan, NJDEP-AQP

Ecological Impacts of Mercury (Bioindicators) - Dr. Gochfeld, EOHSI

Contents, Conclusions and Recommendations of NESCAUM Report – Joann Held, NJDEP-AQP

June 19, 1998

Electric Industry Restructuring Proposal - Steve Gabel, Independent Energy Producers of NJ

Mercury in Sludge: NJDEP Residuals Management Program – Anthony Pilawski, NJDEP Bureau of Pretreatment and Residuals (BPR)

Mercury Emissions from Sludge Incineration: NJDEP Stack Test Data – Mike Aucott, NJDEP-AQM

Handouts on Health Effects Review - Alan Stern, NJDEP-DSRT

Overview of New England Governors Association (NEGA) Mercury Reduction Action Plan – Randy England, NJDEP-DSRT

Summary of Potential Mercury Contamination Reduction Strategies – Minnesota Pollution Control Agency and Committee of States – Mike Winka, NJDEP-DSRT Office of Innovative Technology (OIT)

Task Force Input for Mercury Section of New Jersey Performance Partnership Agreement - Leslie McGeorge, NJDEP-DSRT

Report on New Publications - Dr. Gochfeld, EOHSI

July 17, 1998

Update on Sludge Incineration - Mike Aucott, NJDEP-AQM

Minnesota's Strategy Evaluation Approach - Mike Winka, NJDEP-DSRT/OIT

Task Force Comments on Strategic Plan and Performance Partnership Agreement - Joann Held, NJDEP-AQP

"Greening" Hospitals Report - Dr. Michael Gochfeld, EOHSI

August 7, 1998

Review of Comments on PPA Document - Leslie McGeorge, NJDEP- DSRT

Review of Previous Mercury Task Force Report Recommendations – Randy England, NJDEP-DSRT

Minnesota's Strategy Evaluation Approach – Mike Winka, NJDEP-DSRT/OIT

Source Separation Program – Mike Winka, NJDEP-DSRT/OIT

Mercury Emission Estimates for Hazardous Waste Incinerators - Keith Michels, Safety-Kleen, Inc.

Source Separation Program - Mike Winka, NJDEP-DSRT/OIT

Update on Sludge Incineration - Mike Aucott, NJDEP-AQM

September 11, 1998

Energy Restructuring - Dolores Phillips, Center for Environment and Public Health Policy, and John Guinan, PIRG

Mercury Emission Data by Sources – Bill O'Sullivan, NJDEP-AQP

Discussion of EPA Document, Background Information on Mercury Sources and Regulations - Keith Michels, Safety-Kleen

Pollution Prevention Briefing on Mercury – Melinda Dower, NJDEP Office of Pollution Prevention and Permit Coordination (OPPPC)

Religious and Ceremonial Uses of Mercury – Mike Aucott, NJDEP-AQM

October 9, 1998

Ambient Water Monitoring – Leslie McGeorge, NJDEP-DSRT

Surface Water and Sediment Monitoring – Tom Vernam, NJDEP-Water Monitoring Management (WMM)

Groundwater Network – Mike Serfes, NJDEP-DSRT New Jersey Geological Survey (NJGS)

Mercury in Public and Private Water Supplies – Judy Louis & Eileen Murphy, NJDEP-DSRT

Overview of Models Used to Describe Mercury Fate and Transport -- Joann Held, NJDEP-AQM and Betty Jensen, PSE&G

Discussion of EPA Document, "Developing a Virtual Elimination Strategy for Mercury" - Keith Michels, Safety-Kleen, Inc.

November 13, 1998

Atmospheric Deposition -- Stu Nagourney, NJDEP-DSRT

Available Options for Mercury Source Data Collection – Melinda Dower, NJDEP-OPPPC

A-10 Recommendations Letter to Commissioner Shinn - Dr. Gochfeld, Environmental and Occupational Health Sciences Institute (EOHSI)

Contaminated Sediments Sources and Impacts – Jennifer DiLorenzo, NJ Commerce and Economic Growth Commission, Maritime Resources

Private Wells in Kirkwood-Cohansey Aquifer – Leslie McGeorge, NJDEP-DSRT

December 11, 1998

Groundwater Update – Eileen Murphy, NJDEP-DSRT

EPA and DOE Air Quality Conference: Mercury, Trace Elements and Particulate Matter - Joann Held, NJDEP-AQP

EPA Partnership with American Hospital Association: Mercury Waste Reduction- Chris LaBianco, NJ Hospital Association

January 8, 1999

Mercury in Dental Practices and Waste Materials -
    Bill Prentice, Director of Governmental Affairs, NJ Dental Association
    Jim Murphy, NJDEP-BPR

Senate Bill 1267 on Fish Advisory - Jim Blumenstock, Department of Health and Senior Services

Source Reduction: Mercury Product Recycling - Mike Winka, NJDEP-DSRT/OIT

Emissions & Generation Resource Integrated Database (E-GRID)- Keith Michels, Safety-Kleen, Inc.

February 19, 1999

U.S. EPA Draft Mercury Action Plan - Randy England, NJDEP-DSRT

European Mercury Regulations and Technology - Gerald Hofman, STEAG Company

Mercury Products Recycling - Bob Romano, Comus International

Mercury-containing Products Conference Summary - Mike Winka, NJDEP-DSRT/ OIT

NJDEP Proposal on Mercury Lamps - Mike Winka, NJDEP-DSRT/OIT

Mercury in Groundwater -Leslie McGeorge, NJDEP-DSRT

> Summary of State Activities - Eileen Murphy, NJDEP-DSRT
>
> County Perspective from Health Officers - Pat Diamond, Atlantic County; Don Schnieder, Gloucester County; Bob Ingenito, Ocean County

Energy Restructuring Legislation Update - Mike Winka, NJDEP-DSRT/OIT

Relating Sustainability Concepts to Mercury Task Force - Joann Held, NJDEP-AQP

March 12, 1999

Review of NJDEP Comments on EPA Draft Mercury Action Plan - Randy England, NJDEP-DSRT

Update on Florida Emission Advisory - Randy England - NJDEP DSRT

Update on Task Force Recommendations on Pollution Prevention Rules and NJDEP comments on U.S. EPA PBT proposal (Mercury Threshold Reporting) - Melinda Dower, NJDEP-OPPPC

The Atmospheric and Aquatic Cycles of Mercury - William Fitzgerald, University of Connecticut

April 9, 1999

Religious and Ceremonial Uses of Mercury – Arnold P. Wendroff, Columbia University

Task Force Discussion with NJDEP Commissioner Robert C. Shinn, Jr.:

- Task Force Charge, Progress and Interim Recommendations - Leslie McGeorge, NJDEP-DSRT

- Impacts to Health and Ecological Systems - Dr. Gocheld, Task Force Chair and Alan Stern, NJDEP-DSRT

- Sources of Mercury in the Environment - Bob Morris, The Coastal Corp. and Mike Aucott, NJDEP-AQM

- Proposed Contents of Report and Public Release - Dr. Gochfeld and Leslie McGeorge

May 14, 1999

Department of Health and Senior Services (DHSS) Follow Up to Religious and Ceremonial Uses of Mercury From Discussion at April 1999 Meeting - Jim Blumenstock, DHSS

New ATSDR Minimal Risk Level for Mercury - Alan Stern, NJDEP-DSRT

Proposed Regional Mercury Limit for Medical Waste Incinerators – Mike Winka, NJDEP-DSRT/OIT

June 11, 1999

Sources Subcommittee Meeting – Mark Carney, PG&E Generating

July 16, 1999

NJ Release Reduction Goal: Air and Water - Leslie McGeorge, NJDEP-DSRT

Mercury in Sludge

- Research Needs for Land Applied Sludge – Mary Jo Aiello, NJDEP-BPR

- Characterizing Mercury Content of Sludge for Incineration – Mary Jo Aiello, NJDEP-BPR

- Testing Incinerated Sewage Sludge – Bill O'Sullivan, NJDEP-AQP

Characterizing Mercury Content of Sludge for Land Application – Mike Aucott, NJDEP-AQM

Outreach and Education – Sue Shannon, NJDEP-DSRT

August 13, 1999

Analytical Methods for Water - Eileen Murphy, NJDEP-DSRT

Collection of Mercury-containing Household and Hazardous Waste – Fred Stanger, Association of New Jersey Household and Hazardous Waste Coordinators

September 24, 1999

Mercury in the Environment Conference Sponsored by Air & Waste Management Association - Joann Held, NJDEP-AQP

Natural Gas Regulators – Sheryl Telford, PSE&G

Goal Setting Recommendation and Discussion - Leslie McGeorge, Alan Stern, Mike Aucott, Mike Winka, NJDEP-DSRT

October 8, 1999

NY State Suit Against Mid-West Coal Power Plants – John Elston, NJDEP-AQM

Linking NJ Source Inventory with Regional-Global Sources – Leslie McGeorge, NJDEP-DSRT

November 19, 1999

Linking NJ Inventory with Regional and Global Sources – Leslie McGeorge, NJDEP-DSRT & Joann Held, NJDEP-AQP

Current Mercury Data from the NJ Atmospheric deposition Network – Mike Aucott, NJDEP-DSRT

Mercury Recycling – Bruce Lawrence, Bethlehem Apparatus

December 10, 1999

Follow-up from November's Meeting Presentation on Mercury Recycling - Mike Aucott, NJDEP-DSRT

Regional Draft Model Legislation on Mercury in Waste - Mike Winka, NJDEP-DSRT/OIT

January 14, 2000

Briefing on NEWMOA meeting on Draft Model Legislation for Mercury in Waste - Robin Heston, NJDEP Division of Solid and Hazardous Waste (DSHW)

Review of "Mercury Falling" Report from Natural Resources Defense Council - Betty Jensen, PSE&G

February 18, 2000

NJDEP Comments on Draft Mercury in Waste Model Legislation - Mike Winka, NJDEP-DSRT/OIT

Collection System for Mercury Devices: Thermostats - Mike Winka, NJDEP-DSRT/OIT

Mercury Environmental Progress Briefing to NJDEP Management Team - Leslie McGeorge, NJDEP-DSRT

March 10, 2000

Clean Air Council Public Hearing Task Force Presentation on April 12, 2000 - Dr. Gochfeld, EOHSI

Task Force Suggestions for EPA's Mercury Research Agenda - Dr. Gochfeld, EOHSI

Briefing on Mercury, Toxics Release Inventory and Air Toxics Conference - Betty Jensen, PSE&G and Joann Held, NJDEP-AQP

Mercury Environmental Progress Briefing to NJDEP Management Team - Leslie McGeorge, NJDEP-DSRT

Continuous Emissions Monitoring for Mercury Using Plasma Emission Spectroscopy - Philip Efthimion

Minamata, Japan - Dr. Gochfeld, EOHSI

May 12, 2000

Mercury Environmental Progress Briefing to NJDEP Management Team - Leslie McGeorge, NJDEP-DSRT

Clean Air Council Public Hearing Presentation from the Task Force – Dr. Michael Gochfeld, EOHSI

Overview of Conference: Coordinating Mercury Reduction Programs: A Meeting of National and Local Program Officials - Mike Aucott, NJDEP-DSRT

U.S. EPA/American Hospital MOU- Andy Bellina, EPA Region 2, RCRA

Management of Dredged Materials -
    Introduction - Mike Aucott, NJDEP-DSRT
    Larry Baier, NJDEP Office of Dredging and Sediment Technology (ODST)

June 23, 2000

Impacts of Dredging and Dredged Materials - Mike Aucott, NJDEP-DSRT and Bill Baker, EPA Region 2, Air

Air Deposition - Mike Aucott, NJDEP-DSRT

July 21, 2000

National Research Council Report on the Toxicological Effects of Methylmercury - Alan Stern, NJDEP-DSRT

Possible Mercury Releases in Dredging Operations - Mike Aucott, NJDEP-DSRT

Task Force Recommendations Associated with Energy Restructuring - Mike Winka, NJDEP-DSRT/OIT

August 18, 2000

Task Force Recommendations Regarding Dredging - Mike Aucott, NJDEP-DSRT

September 22, 2000

Coal Discussion - Mike Aucott, NJDEP-DSRT

October 13, 2000

Review of Workshop: Scientific Perspectives on Mercury Management in the Hudson-Delaware Region presented by Society of Environmental Toxicology and Chemistry (SETAC) - Leslie McGeorge, NJDEP-EP&S

Review of NESCAUM Report: Environmental Regulation and Technology Innovation Controlling Mercury Emissions from Coal-fired Boilers, September 2000- Sunila Agrawal, NJDEP-AQP

December 1, 2000

Mercury-related Aspect of Surface Water Quality Standards Rule Proposal - Leslie McGeorge, NJDEP-EP&S

Draft Sources Subcommittee Recommendations - Mike Aucott, NJDEP-DSRT

January 5, 2001

Review of ECOS Conference - Leslie McGeorge, NJDEP-EP&S; Bill O'Sullivan, NJDEP-AQP; Sue Shannon, NJDEP-DSRT

EPA Mercury Research Plan - Andy Bellina, EPA Region 2

Summary of EPA Methylmercury Water Quality Criteria - Gary Buchanan, NJDEP-DSRT

Outreach to Iron and Steel Industry - Leslie McGeorge, NJDEP-EP&S

EPA Mercury in Coal Decision - Bill O'Sullivan, NJDEP-AQP

February 9, 2001

Video Clip from 60 Minutes Program on Fish Consumption - Alan Stern, NJDEP-DSRT

Mercury Emission Limit Options for Coal Discussion of Recommendations - Bill O'Sullivan, NJDEP-AQP

Ritualistic Uses of Mercury - Andy Bellina, EPA Region 2, RCRA

March 16, 2001

Report on ECOS Mercury Resolutions and Workshop - Leslie McGeorge, NJDEP Environmental Planning and Science (EP&S)

Proposed Bill to Ban Mercury-containing Thermometers - Michael Gochfeld, EOHSI

Iron and Steel Presentation - Paul Waxmonsky, U.S. Pipe and Foundry

Iron and Steel Industry Recommendations - Bill O'Sullivan, NJDEP-AQP and Mike Aucott, NJDEP-DSRT

Aluminum Scrap Processing Industry Recommendations - Bill O'Sullivan and Mike Aucott

April 20, 2001

NJ Bill to Ban Mercury-containing Thermometers - Dr. Gochfeld, EOHSI and Leslie McGeorge, NJDEP-EP&S

INFORM's Meeting with Assemblyman Sires - Janet Cox, INFORM

Senator Leahey Bill for FDA Action - Bill Baker, EPA Region 2 Air and Alan Stern, NJDEP-DSRT

Iron and Steel Issues - Tomasz Wesolowski, Co-Steel Inc., Toronto, Ontario
    Michael Murphy, Co-Steel Raritan, Perth Amboy
    Paul Waxmonsky, U.S. Pipe and Foundry Co., Burlington
    Timothy Panaski, Griffin Pipe Products, Florence
    Daniel Yadzinski, Atlantic States Cast Iron Pipe Company, Phillipsburg

May 11, 2001

NJ Bill to Ban Mercury-containing Thermometers - Leslie McGeorge, NJDEP-EP&S

Federal Mercury Legislation - Mike Aucott and Alan Stern, NJDEP-DSRT

Iron and Steel Follow-up Discussion on Write-up, Recommendations and Inventory - Sunila Agrawal, NJDEP-AQP and Mike Aucott, NJDEP-DSRT

June 15, 2001

NJDEP Comments on NJ Bill to Ban Mercury-Containing Thermometers - Leslie McGeorge, NJDEP-EP&S and John Hazen, NJDEP Legislative Affairs

U.S. EPA Workshop on Ritualistic Uses of Mercury - Andy Bellina, EPA Region 2, RCRA

Mercury Storage in Somerville, NJ - Michael Gochfeld, EOHSI

Update on Northeast Governors/Eastern Canadian Premiers Conference - Randy England, NJDEP-DSRT

July 13, 2001

Mercury-containing Products - Mike Aucott, NJDEP-DSRT and Mike Winka, NJDEP-DSRT/OIT

Mercury Storage in Somerville, NJ - Allan Edwards, NJDEP Release Prevention Element
Robert Kotch, NJDEP Bureau of Discharge Prevention
Larry Schmidt, NJDEP Office of Coastal Planning & Program Coordination

August 24, 2001

Mercury Management Environmental Impact Statement Presentation - Kevin Reilly, Environmental Management for the Defense National Stockpile Center

September 14, 2001

ECOS Mercury Resolutions - Leslie McGeorge, NJDEP-EP&S

Report Review - Mike Gochfeld, EOHSI; Alan Stern and Mike Aucott, NJDEP-DSRT

September 28, 2001

Executive Summary and Recommendations - Mike Aucott and Alan Stern, NJDEP-DSRT

APPENDIX VII

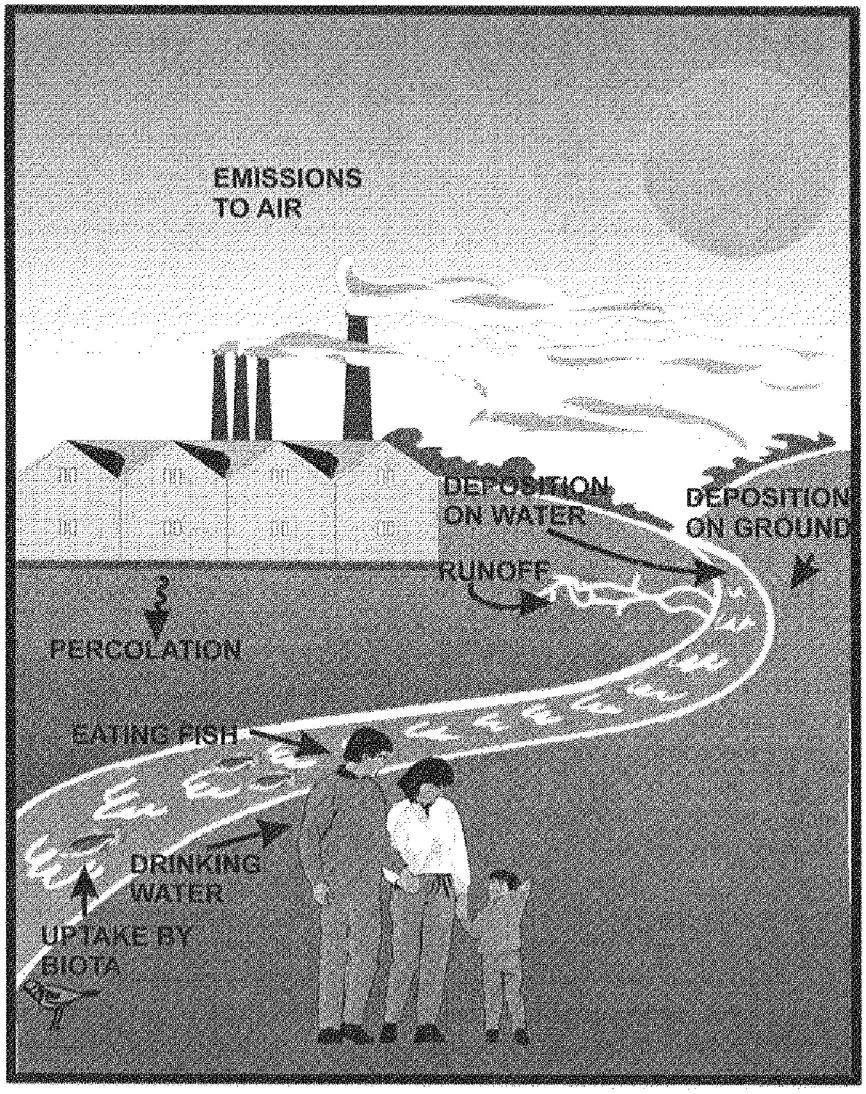
Acronyms

µg /L	microgram per liter
ATSDR	Agency for Toxicology and Disease Registry
DNSC	Defense National Stockpile Center
ECOS	Environmental Council of States
EOHSI	Environmental and Occupational Health Sciences Institute
HEP	Harbor Estuary Program
Hg	Mercury
Hg(II)	Inorganic mercuric
Hg^{++}	Inorganic mercuric
Hg^{o}	Elemental mercury
Hg_{p}	Particulate mercury
HgS	Mercury Sulfide
MCL	Maximum Contaminant Level
MeHg	Methylmercury
Mg/MW-hr	Milligram per milliwatt hour
MSWI	Municipal Solid Waste Incinerators
NEGA/ECP	New England Governors Association- Eastern Canadian Premiers
NEPPS	National Environmental Performance Partnership System
NESCAUM	Northeast States for Coordinated Air Use Management
NEWMOA	Northeast Waste Management Officials' Association
ng/L	nanograms per liter
NJBPU	New Jersey Board of Public Utilities
NJDEP	New Jersey Department of Environmental Protection
NJDHSS	New Jersey Department of Health and Senior Services
NJDOT	New Jersey Department of Transportation
NRC	National Research Council
NSCRF	National Study of Chemical Residues in Fish
PCBs	Polychlorinated biphenyls
POET	Point of entry treatment
ppb	Part per billion
ppm	Part per million
ppt	Part per trillion
PSE&G	Public Service Electric & Gas

RfC	Reference Concentration
RfD	Reference Dose
TMDL	Total Maximum Daily Load
U.S. EPA	United States Environmental Protection Agency
UMDNJ	University of Medicine and Dentistry of New Jersey
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WQC	Water Quality Criterion

New Jersey Mercury Task Force

Volume II:
Impacts of Mercury in New Jersey



January, 2002

Prepared for New Jersey Department of Environmental Protection

New Jersey Mercury Task Force Report
Volume II
Exposure and Impacts

January, 2002

New Jersey Mercury Task Force

Donald T. DiFrancesco Acting Governor	Robert C. Shinn, Jr. Commissioner

State of New Jersey
Department of Environmental Protection

Christine Todd Whitman
Governor

Robert C. Shinn, Jr.
Commissioner

Department of Environmental Protection
Commissioner's Office
401 East State Street, 7th Floor
P.O. Box 402
Trenton, NJ 08625-0402

Dear Reader:

Mercury is a persistent, bioaccumulative, toxic pollutant. An organic form of mercury (methylmercury) has been found at unacceptably high levels in certain fish, and can cause serious health effects in some fish consumers. Other exposure routes are also potentially important, including exposure to primarily inorganic forms of mercury in some private well water.

Through a combination of source reduction and aggressive pollution control measures, we in New Jersey, have achieved some very notable reductions in the environmental releases of mercury over the past decade including reductions in emissions from municipal solid waste and medical waste incinerators.

More significant reductions are feasible and necessary. The Mercury Task Force recommends a strategic goal of an 85% decrease in in-state mercury emissions from 1990 to 2011. (This goal equates to a 65% decrease from today to 2011.) At my request, the Mercury Task Force has diligently assembled a vast body of information to serve as the basis for a comprehensive set of recommendations to reduce the environmental impacts of mercury releases. These recommendations are designed to provide New Jersey with its first comprehensive mercury pollution reduction plan. Implementation of these recommendations will limit mercury exposures to our citizens and our wildlife.

I would like to thank all of the Task Force members for their hard work and dedicated service to the citizens of New Jersey, and I am pleased to accept this comprehensive Mercury Task Force Report. I urge legislators, government officials, the environmental community, business and industry, the scientific and technical community, and all other interested citizens to review this report and determine how they can most effectively work in partnership with the New Jersey Department of Environmental Protection and other state agencies, to achieve these important New Jersey mercury reduction goals.

Sincerely,

Robert C. Shinn, Jr.
Commissioner

E O H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES INSTITUTE

University of Medicine & Dentistry of New Jersey
Department of Environmental and Community Medicine
EOHSI Building---170 Frelinghuysen Road
Piscataway, NJ 08854
Phone 732-445-0123 X627 FAX 732-445-0130
email "gochfeld@eohsi.rutgers.edu"

November 2001

Commissioner Robert C. Shinn, Jr.
NJ Department of Environmental Protection
P.O. Box 402
Trenton, NJ 08625-04002

Dear Commissioner:

The members of the Task Force are pleased to submit to you our recommendations for reducing mercury impacts to the environment.

Mercury is a highly toxic material that has no known essential biological properties. It is toxic to adults, but the main health concern today is its potentially profound impact on the developing nervous system and the concern that fetal development can be significantly altered by even low levels of mercury (particularly methylmercury) in the mother's diet. This growing concern, spurred by recent epidemiologic research, has led many governments and other groups to address the problem of mercury in the environment.

Mercury's unique physical properties have led to its use for centuries in a wide variety of commercial applications and industrial processes. Its toxic properties have also been exploited in medicine, dentistry, agriculture, and paint manufacture. Although most uses have been eliminated or reduced (for example, mercury fungicides and batteries), or are being phased out today (for example, mercury thermometers), mercury remains in commerce in a number of forms including dental amalgams, fluorescent lights, thermostats, and certain electric switches.

Today, however, many of the most serious sources of mercury are inadvertent. These include the burning of waste, the use of coal to generate electricity, and the recycling of a variety of mercury-containing products, such as metals. Recognizing that toxic methylmercury occurred at surprisingly high levels in some freshwater fish from many waterbodies in the State, the New Jersey Department of Environmental Protection convened the first Mercury Task force in 1993. This advisory group concluded that emissions from municipal solid waste incinerators were, at that time, the main controllable sources of mercury emissions in the state. Its recommendations and subsequent regulations led to a major reduction in mercury emissions from New Jersey incinerators; the targets set by the first Task Force for this particular industrial sector have been met and surpassed.

It has been my privilege to chair the second Mercury Task Force, convened in 1998 by Commissioner Robert C. Shinn, Jr., which has tackled a much wider array of mercury sources. Triggered, in part, by the concern that energy deregulation would increase the output from midwestern power plants which, as a whole, have relatively high emissions including mercury, the Task Force had to grapple at the outset with recommendations to assure that New Jersey's own energy deregulation law would not exacerbate New Jersey's mercury pollution problem. The Task Force went on to inventory many other sources of mercury to the environment, some of them unanticipated.

Our work has been rendered at times easier, and at times more difficult, by the many reports from federal agencies, other states, non-governmental organizations, and public interest groups that have appeared during the lifetime of the Task Force. New Jersey is by no means alone in considering various approaches, including legislation, to reduce mercury uses and emissions. It has indeed been an exciting time to learn about mercury.

For three years now I have had the opportunity to work with and learn from many dedicated and knowledgeable Task Force members and NJDEP representatives. We have also benefited from the numerous presentations made to the Task Force by outside groups, each with unique knowledge and perspectives. They are identified in Appendix VI.

Work on a voluntary Task Force of this nature is extremely demanding of time and energy. A number of Task Force members and other stable participants were indefatigable in their participation, and I particularly want to thank:

William Baker
Andrew Bellina
Janet Cox
Daniel Cunningham
Robert Dixon
Tom Fote
Betty Jensen
Russ Like
Jerry Marcus
Leslie McGeorge (NJDEP Representative)
Keith Michels
Robert Morris
Joel O'Connor
Valerie Thomas
Robert Tucker

Also, Dolores Phillips played a very active role in the origin and early deliberations of the Task Force.

Many NJDEP representatives contributed to the research and writing of the report. All are listed in Appendix IV.

I particularly thank Bob Morris, Alan Stern and Michael Aucott whose time commitments to the Task Force were great and who each co-chaired one of the two working sub-committees (Impacts and Sources). Leslie McGeorge coordinated all NJDEP technical support for the Task Force, kept the Task Force focused on its charges and integrated its work with other NJDEP projects and programs. Sue Shannon coordinated various aspects of the Task Force and managed the communications and planning of meetings.

Other NJDEP staffers who made major contributions include:

Sunila Agrawal
Alan Bookman
Gary Buchanan
Robert Confer
Jim DeNoble
Mary Downes-Gastrich
Randy England
Joann Held
Mike McLinden
Eileen Murphy
Bill O'Sullivan
Anthony Pilawski
Bruce Ruppel
Michael Winka

I personally thank Commissioner Shinn for the thoughtful organization of the Task Force and his patience in awaiting this report. I trust that it will prove valuable in helping New Jersey and the Nation grapple with an insidious pollutant and reduce its impact on future generations. I echo his charge, that the lessons learned from mercury toxicity, mercury pollution and mercury control, should also help us in reducing human and ecosystem exposure to other environmental hazards which can threaten our growing population.

Sincerely yours,

Michael Gochfeld, MD, PhD
Chair

Charge to the Mercury Task Force
From Administrative Order 1998-08
Signed by Commissioner Shinn in March 1998

The mission of the Task Force is to develop a mercury pollution reduction plan for New Jersey. The Task Force is directed to complete the following tasks:

1. Review the current science on: a) impacts of mercury pollution on public health and ecosystems; and b) mercury deposition, transport, and exposure pathways.

2. Inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution.

3. Utilizing available information, quantify mercury pollution's impact on New Jersey's ecosystems, public health, and tourism and recreation industries.

4. Review New Jersey's existing mercury pollution policies.

5. Develop a mercury pollution reduction plan for the State of New Jersey, including:
   A) Recommend mercury emission controls and standards for in-state sources, including: coal fired generators; hazardous waste incinerators; sludge incinerators; hospital waste incinerators; and for other sources deemed necessary by the task force. In recommending controls and standards, the task force will explore renewable energy and alternative fuels to mercury emitting fuels now in use, and review innovative and low cost emission reduction strategies available in various industrial sectors.
   B) Provide timely interim recommendations, as feasible, prior to completion of the task force's overall mission, to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls and standards and the relationship of energy deregulation to mercury pollution.

NJ Mercury Task Force
Final Report

Volume I
Executive Summary and Recommendations

Volume II
Exposure and Impacts

Volume III
Sources of Mercury to New Jersey's Environment

TABLE OF FIGURES

TABLE OF TABLES

Chapter 1 – FORMS OF MERCURY IN THE ENVIRONMENT

A. Introduction

Mercury, a heavy metal, has unique properties. It is liquid at ambient temperature and is approximately 14 times heavier than water. The main mercury ore is cinnabar (mercuric sulfide or HgS), which has been mined at relatively few places on earth. The mines of Idrija (now in Slovenia) operated for more than 500 years until closed in 1995 (Biester et al. 2000). The mercury mines at Almaden, Spain, have operated since 415 B.C. (Hunter 1974). Pliny called it "hydrargyrum" (liquid silver) from which comes the abbreviation on the Periodic Table of the elements, 'Hg'. Its poisonous properties were known to the Romans. The familiar droplets known as "quicksilver" are elemental mercury (Hg^0) and give off mercury vapor. All forms of mercury are toxic to humans and to virtually all other forms of life. Its unique physical properties (heavy liquid) at room temperature have enabled its use for a variety of uses such as in mercury switches, thermostats, thermometers, and other instruments. Its toxic properties (see Volume II Chapter 5) have enabled its use as medications, antiseptics, and pesticides. For these reasons there have been many industrial uses of mercury, leading to health and environmental consequences: occupational exposures of workers; industrial emissions and effluents; and contamination of air, water, soil, and ultimately food chains.

Mercury occurs at very low concentrations in sea water and in soils. There are very few locations on earth where it has been found in concentrations high enough to be mined. Of increasing concern is the fact that mercury occurs in coal. Although mercury is a minor constituent of coal, the reliance on coal as a source of electricity has made it a significant and increasing source of environmental mercury, at the same time that other sources (industrial effluents, incinerator emissions) have declined. Today, the major sources of mercury for the general environment include burning of coal to produce electricity and the incineration of wastes. New Jersey's first Mercury Task Force addressed the latter source and its success is evident by the tremendous reduction already achieved in mercury emissions from waste incinerators.

The first of these sources, coal-fired power plants, remains an important source of mercury and other toxic air pollutants, particularly in the face of increasing demands for electricity imposed by growing populations and increased industrialization. The deregulation of electric power in the United States and in New Jersey may exacerbate the problem since older and cheaper plants will be able to increase their market share of electricity by accessing markets formerly closed. At the same time, a failure to develop renewable energy sources or achieve energy conservation may mean that mercury pollution from coal-fired power plants will increase.

The Task Force has identified many other sources of mercury, most of which can be readily controlled, and some of which can be eliminated. The Task Force has obtained data that allows quantitative estimates of the releases from each source (see Volume III).

Organizing the information on mercury in a coherent manner was challenging. Chapters 1-6 of this volume provide information on mercury in general, while chapters 7-11 focus on mercury in NJ. Although Task Force members and DEP staff found abundant information on mercury, there remain many gaps in knowledge.

B. Organic Mercury

The forms or species of mercury are usually classified into the broad categories of organic and inorganic. They have different physical, chemical and toxicological properties. There are several forms of organic mercury, including phenylmercuric acetate, dimethylmercury and monomethyl mercury (ATSDR 1999a). Monomethylmercury, usually referred to simply as methylmercury (MeHg), is the most widespread organic form in the environment and is the toxic form of greatest concern to the environment. It has been demonstrated that in aquatic systems anaerobic bacteria can convert inorganic mercury to organic mercury forms (WHO 1990). Both dimethylmercury and monomethyl mercury is formed in aquatic systems; however, dimethylmercury is highly volatile and is rapidly and essentially completely released through the water column to the atmosphere, particularly in fresh waters. Methylmercury compounds also occur, usually at trace concentrations. MeHg is, in fact, an ion (CH_3 -Hg^+), which is found in association with various anions (negatively charged ions) such as sulfate, chloride and hydroxide. In organisms, MeHg is bound mainly to sulfur in amino acids, protein, glutathione and related compounds (NRC 2000). Exposure of humans to MeHg is almost exclusively through consumption of fish (ATSDR 1999a). Mammals and birds may be exposed to MeHg through consumption of fish, consumption of other fish-eating species, or through consumption of lower order biota, such as insects and plankton, which also incorporate MeHg, albeit at lower concentrations (USEPA 1997d).

Methylmercury poisoning of humans was first recognized at Minamata, Japan around 1960. Hundreds of fishermen and their families were severely poisoned during the 1950's by methylmercury that bioaccumulated in fish due to release of mercury to the bay from a local chemical plant. A similar episode occurred in the 1960's in Niagata, Japan. Epidemics of organic mercury poisoning from consumption of grain treated with organomercurial fungicides have also occurred in Iraq and Guatemala. A family in New Mexico was poisoned by eating pork from their pigs which they had fed on fungicide-treated grain.

C. Inorganic Mercury

The inorganic forms of mercury include elemental mercury (Hg^0) which is unique among metals in being liquid at ambient temperature and being quite volatile. It exists in equilibrium between the liquid and vapor forms. There are two ionic forms of mercury, mercuric Hg^{++} and mercurous Hg^+. The mercuric form is more environmentally stable, and therefore predominates. Hg^{++} is commonly found as mercuric chloride ($HgCl_2$), and mercuric sulfide (HgS). Cinnabar, the most common mercury ore, contains HgS. $HgCl_2$ is soluble in water (1 g/35ml) (ATSDR 1999a) and is a relatively common form of inorganic mercury in aquatic systems, the atmosphere, and in aerobic soils. HgS is the most stable of the common inorganic species and is essentially insoluble in water (ATSDR 1999a). It thus tends to function as a long-term sink for environmental mercury in soils and sediments. Mercury has a high affinity for sulfur, and under a variety of conditions it will bind strongly to either inorganic or organic sulfur. Since proteins (including all enzymes) contain sulfur, and the cross linkages between sulfur confers important structural and functional properties, mercury has the capability of interfering with a great many biochemical reactions by disrupting these disulfide bonds. Other forms of Hg^{++}, such as mercuric sulfate ($HgSO_4$) and mercuric oxide (HgO), are potentially important in atmospheric processes, but they tend to be short-lived in the environment (Mason et al. 1994). Those forms of Hg^{++} that are moderately soluble (e.g. $HgCl_2$) can contaminate surface and groundwater and are largely responsible for the elevated levels of mercury in private wells in areas of southern New Jersey.

Exposure to elemental mercury occurs in certain workplaces, in health care facilities, and occasionally in homes. The droplets of mercury are attractive, and children have been known to bring mercury home to play with. The cultural practice of Santeria also results in household exposures to elemental mercury. Breakage of thermometers and spills from gas meters during their removal are infrequent, but important sources of mercury. When such spills occur it is important that they be cleaned up quickly. Information on how to do this is available at the NJDHSS web site address http://www.state.nj.us/health/eoh/survweb/merchome.pdf.

Liquid droplets will give off toxic mercury vapor which can be inhaled by the occupants. Globules of Hg^0 may persist for a long time before they evaporate completely. However, they may be more stable under anaerobic conditions under water or in the soil where they can become coated with a stable layer of insoluble HgS. Unless these globules are transferred to an oxidizing environment (due to dredging of sediment for example), such deposits of coated Hg^0 can remain inert for a long time. This may be important in moderating the migration of Hg^0 in landfills, for example.

Hg^0 vapor in the atmosphere is subject to long range transport. Hg^0 is slightly soluble in water (0.08 mg/l at 25°C) (ATSDR 1999a) and a small fraction of Hg^0 vapor can, therefore, be washed out of the atmosphere during precipitation events. The more likely fate of Hg^0 however, is eventual oxidation to Hg^{++} by reaction with atmospheric oxidants such as oxygen, ozone, and chlorine (Mason et al. 1994). Once converted to the Hg^{++} form, the mercury is much more soluble and more subject to washout of the atmosphere with precipitation. This is called "wet deposition" and is a major source of mercury input to the environment. A small amount of the mercury may adhere to fine particles in the atmosphere and may fall out without rainfall as "dry deposition". Dry deposition also includes gaseous mercury and mercury compounds that are directly absorbed by plant foliage, soils and other media. The relative contribution of wet and dry deposition is variable and not well quantified.

Chapter 2 - OCCURRENCE OF MERCURY IN ENVIRONMENTAL MEDIA

A. Introduction

The issue of mercury in the environment has generated several important reports that reflect the evolution of our understanding of ecotoxicology and environmental science. Beginning in the 1960's, Swedish scientists played a lead role, partly because the widespread use of mercurial fungicides to protect grain during the long Scandinavian winters had resulted in extensive poisoning of granivorous and raptorial birds. The report by Lofroth (1970) on methylmercury toxicity and the volume *The Biogeochemistry of Mercury in the Environment* (Nriagu 1979) summarized much of the early research.

Given the mobility of mercury in the environment and its ability to bioaccumulate in food chains, knowledge of the occurrence of mercury in various environmental media is critical to understanding and predicting both human and ecological exposures and risk from mercury. Figure 2.1 shows some of the complexity of mercury exposure pathways.

Figure 2.1.
The complexity of various mercury exposure pathways.

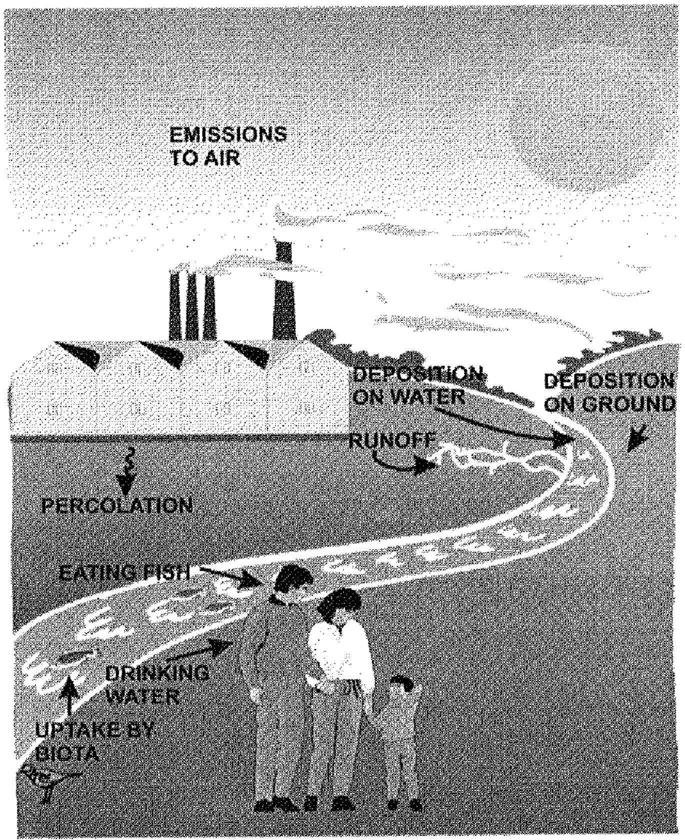


Table 2-1 shows how various sources contribute to potential exposure pathways for methylmercury (MeHg), ionic mercury (Hg^{++}), and elemental mercury (Hg^0). Where data are available, the table provides estimates of daily exposure relevant to New Jersey.

Organomercurials are readily absorbed through the skin and can lead to fatal poisoning, but this is likely to occur only during occupational contact with the materials. It is not likely that handling fish muscle during preparation results in any dermal or inhalation absorption. These pathways are not included in Table 2-1.

Table 2.1. Sources and Estimates of Daily Human Exposures to Mercury. **(Unless otherwise indicated, exposures are estimates of average daily intake in NJ and/or nationwide.)**

Source of Exposure	Methylmercury (MeHg) (μg/day)	Inorganic Hg Salts (Hg^{++}) (μg/day)	Elemental Hg (Hg^0) (μg/day)
Foods (non-fish)	Negligible	0.9[a]	Negligible
Commercial fish	6[b]	<1[c]	Negligible
Sport fish	No population-based data available	No population-based data available	Negligible
Public supply water	Negligible	<<4 [d]	Negligible
Private wells	Negligible	0.4-4 (45% of exposed population) <4 (14% of exposed population) For consumers of water from selected wells in southern NJ[e]	0.006-0.03 (by inhalation in a shower) [e,f] (For consumers of water from selected wells in southern NJ with total Hg concentration > 2 μg/l)
Outdoor air	Negligible	Negligible	0.04 - 0.2[g]
Indoor air	Negligible	Negligible	No population based data available
Soil ingestion	Negligible	>3 [h] For sites exceeding NJDEP soil cleanup criterion for Hg	Negligible
Dental amalgams	Negligible	Negligible	.3-17 μg depending on number and age of fillings[a]

a. (ATSDR 1999a) based on nationwide 1982-1984 US FDA Total Diet study.
b. (Stern et. al. 1996) based on NJ fish consumers, general population.
c. Based on assumption that MeHg accounts for >90% of total mercury in fish.
d. Based on lack of systematic exceedance of drinking water Maximum Contaminant Level (MCL) for inorganic mercury, and assuming 2 L/day of drinking water consumption.
e. (USGS 1997). Based on 2,239 (non-randomly) selected private wells in southern NJ. [NB: Because wells were not selected at random this value cannot be extrapolated to the general population.]
f. See Volume II, Chapter 7 Occurrence and Impact of Mercury in New Jersey's Environmental Media, "Water in Private Wells" of this report for details of assumptions and modeling) based on average concentration of "volatile" mercury in wells exceeding 2 µg /l total mercury. Assumes mercury identified as "volatile" mercury is elemental mercury. Assumes 10-50% volatilization of elemental mercury during a 15 minute shower. (ATSDR 1999a). Based on 1980 US EPA estimate of nationwide average ambient air mercury levels of 2-10 ng/m^3, and assumed breathing rate of 20 m^3/day.
h. Applies only to sites exceeding NJDEP cleanup criterion for total mercury. Assumed to be inorganic mercury (Hg^{++}), and assuming average daily soil ingestion of 200 mg/day. Assuming 100% bioavailability for total mercury by ingestion. This value cannot be extrapolated to the general population.

B. Absorption and Bioavailability

Bioavailability refers to the ability of mercury to be transferred from one matrix to biological tissue, i.e. from water or sediment to biota, or from air, soil or food into an organism. Bioavailability depends on the properties of the matrix and the form of the mercury. The term external bioavailability is sometimes used to distinguish the transfer of mercury from environmental media into an organism, while internal bioavailability refers to the ability of mercury to be transferred from one compartment to another within an organism.

Environmental mercury in soil or sediment is not always available for methylation by bacteria. Using chemical extraction procedures, Martin-Doimeadios et al. (2000) isolated a sulfide form and found no organic mercury being formed. How long such a situation would last is not known. Benoit et al. (2001a) have quantified the impact of adding sulfide to bacterial cultures, showing a fourfold decrease in methylation as sulfide concentration was increased from micromolar to millimolar concentration. They postulate that the concentration of a neutral dissolved Hg-sulfide species is the critical factor (Benoit et al. 2001b).

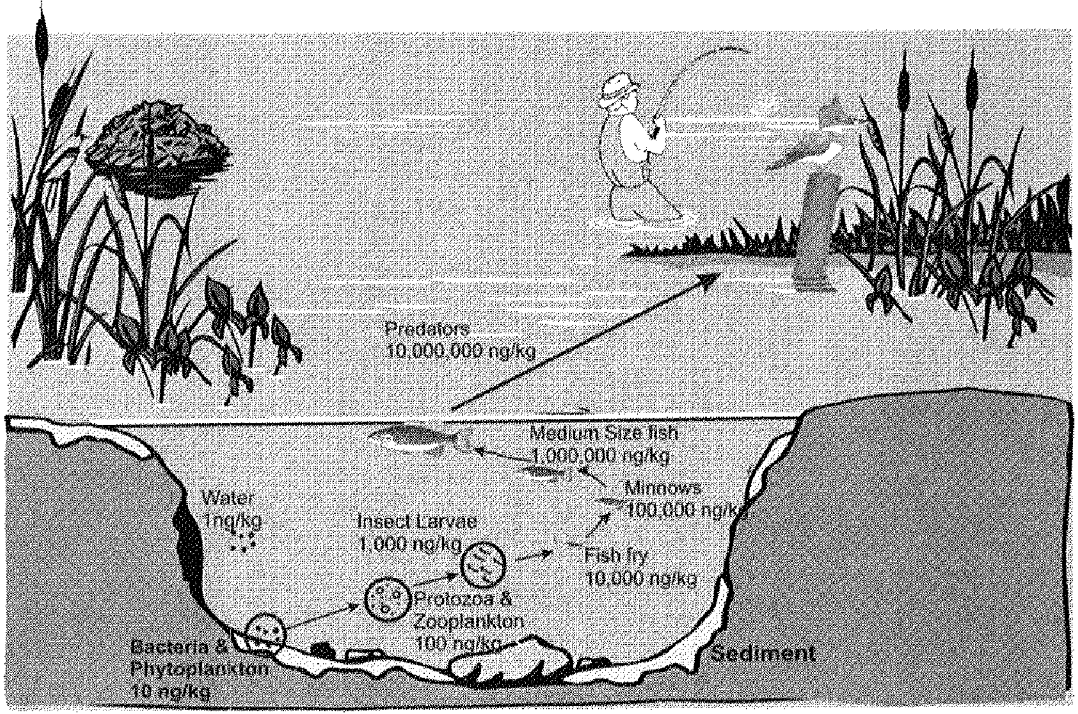
Substances that enter the intestinal tract or the lungs do not necessarily gain access to the blood stream or reach critical target organs. The amount that is transferred depends on two related phenomena: absorption and bioavailability. The intestinal tract and the lungs differ in their absorptive properties for each mercury species, and absorption may vary by age, frequency of meals and other dietary factors. It is generally recognized that elemental mercury vapor is readily absorbed through the lungs (50-100%), but that absorption of liquid elemental mercury from the intestinal tract is negligible (much less than 1%). On the other hand, MeHg is readily absorbed from the intestinal tract (close to 100%) and from the lungs.

Whereas absorption is a property of the body, bioavailability reflects the nature of the medium or matrix. Certain substrates will bind mercury with greater strength or affinity, making it more difficult for the intestine to extract the mercury so it can be absorbed. Unfortunately, there are relatively few studies of the bioavailability of MeHg in different materials, so for risk assessment purposes it is assumed to be 100% in both lungs and intestinal tract. MeHg is also absorbed through skin.

C. Methylmercury (MeHg) in Environmental Media

Inorganic mercury (Hg++) falls on the water surfaces or runs off from the surrounding land and settles to the bottom sediment where bacteria transform it to methylmercury (MeHg) through the process of biomethylation. A typical pattern of biomagnification is shown in the conceptual illustration in Figure 2.2. It begins with a hypothetical water concentration of 1 ng/kg (or 1 part per trillion, 1ppt). After methylation, the MeHg is readily absorbed and retained by any organism in the food chain. Each organism eventually bioaccumulates mercury to a concentration about 10 times greater than in its food. Hence bacteria and phytoplankton would have 10 ng/kg (or 10 part per trillion, 10 ppt). The next trophic levels, protozoa and zooplankton, would accumulate 100 ng/g and so on up the food chain until human or other predators (illustrated by a kingfisher) consume fish with 1 million ng/kg or a 1 ppm concentration. The predators would then achieve concentrations of 10 ppm in their tissue. The entire process is referred to as food chain biomagnification.

Figure 2.2. Typical Pattern of Mercury Biomagnification.



Biomagnification of Mercury

1. *Methylmercury in Food*

Because MeHg is created in aquatic systems, human exposure to MeHg is almost entirely confined to consumption of aquatic organisms. In theory, human exposure could occur through consumption of fish-consuming birds and terrestrial animals such as osprey, eagles, pelicans, and bears. In practice, however, such animals are highly uncommon sources of food for humans in most places, although human populations of oceanic islands often consume fish-eating seabirds. In a survey of food analyses from 10 state food laboratories conducted in 1988-1989, MeHg was found above detection levels in only 0.09% of 13,980 samples (summarized in ATSDR 1999a). Thus, fish consumption poses the only significant source of dietary exposure to MeHg for most Americans. Details on MeHg exposure through fish consumption are provided in Chapter 4 of this Volume. People who consume wild game frequently may also be at increased risk. For example, some studies of duck muscle showed levels ranging from 0.5 ppm in vegetarian ducks up to 12.3 ppm in fish-eating ducks (Vermeer et al. 1973). Fortunately, most consumers of wild duck meat avoid the fishy-tasting fish-eating species.

Fish are widely recognized to be a valuable source of protein with lower cholesterol than red meat, and some species also are rich in omega-3 fatty acids which are believed to be particularly healthful. Yet the consumption of fish varies greatly from country to country and within countries by location, ethnic group, socioeconomic class and dietary preference. But it has long been recognized that people who consume large quantities of fish can have excessive exposure to bioaccumulative pollutants such as organochlorines and methylmercury. In the United States and in New Jersey, most people eat fish occasionally, but some eat fish frequently. Those who eat fish daily may accumulate sufficient quantities of MeHg to become symptomatic. This is examined in more detail in Chapter 9 Section B.

2. *Methylmercury in Soil*

In most soil studies where mercury has been included as an analyte, the mercury is not speciated. Therefore, there is little direct information on MeHg levels in background soils. Some information exists on MeHg levels in soils at hazardous waste sites and in soils after sewage sludge application.

There is recent evidence that a small, but potentially significant fraction of the total mercury in municipal sludge and sludge-derived compost is MeHg. Carpi et al. (1998) found that routine application of municipal sewage sludge to soil increased the concentration of MeHg in the soil from 0.3 μg/kg to 8.3 μg/kg (8.3 ppb).

In a recent study of the speciation of mercury in the soil at a NJ hazardous waste site with extensive mercury contamination, organic mercury appeared to constitute up to 0.2% of the total mercury with a maximum concentration of 500 ppb. The mercury contamination at this site apparently originated as Hg^0 and, since this site is not a wetland, the organic mercury presumably resulted from methylation of inorganic mercury in situ (PTI 1997). In theory, the occurrence of MeHg in the soil resulting from natural wetlands processes, sludge application, or disposal of inorganic mercury hazardous waste, poses the potential for MeHg exposure through ingestion of soil (ATSDR 1999a). Since a 15 kg child is assumed to ingest approximately 200 mg of soil per day through normal hand-to-mouth activities (EPA 1992), and the current USEPA Reference Dose for methylmercury is 0.1 μg /kg-body wt/day, soil would have to be contaminated with 7.5 μg MeHg/g soil in order for soil ingestion to result in exceedance of the Reference Dose. Although much higher levels occur at certain hazardous waste and former industrial sites, most soil samples have much lower levels than this. The presence of MeHg in soil could also result in MeHg uptake into edible plants. There is substantial literature on mercury concentrations in plants, but very little specifically measures MeHg. MeHg is taken up by salt marsh grasses and freshwater plants (Ribeyre and Bouduo 1994), hence this little studied pathway could be important for MeHg under some circumstances. Although mercury concentrations have been measured in a wide variety of foods, with concentrations mainly below 100 ppb, there is virtually no information on MeHg in terrestrial food crops. Since food crops are known to be an important route of exposure to cadmium (McLaughlin and Hamon (2001)) it is prudent to study mercury accumulation in crops. The occurrence of MeHg in soil is of potential significance when runoff from the soil results in transport of even small amounts of MeHg to waterbodies.

3. Methylmercury in Air

Only a small amount of airborne mercury is MeHg. A Reference Concentration (specific to the inhalation route of exposure) for MeHg has not been derived. However, if the standard inhalation rate of 20 m^3/day is assumed for a 70 kg adult, and it is conservatively assumed that 100% of inhaled MeHg is taken up by the circulating blood, the current USEPA Reference Dose can be calculated to be equivalent to an air concentration of 0.35 $\mu g/m^3$. This estimate is intended strictly for purposes of comparison since it does not address potential differences in metabolism of ingested and inhaled mercury. There are few reports of ambient air levels of MeHg (Brosset and Lord 1995; Fitzgerald et al. 1991; Prestbo and Bloom, 1994). Available data indicate levels of 3 to 38 pg/m^3 (MeHg), which is about 0.01% of the air concentration calculated above. Since MeHg has a low vapor pressure, and tends to bind tightly to organic and biochemical molecules, release of MeHg from aquatic systems would not be expected to be significant from the standpoint of inhalation exposures on or near waterbodies. Carpi et al. (1998) reported on the release of MeHg from sludge amended soil, but the concentration of MeHg in the soil was low and the amount of MeHg released to the atmosphere was not significant from the standpoint of local exposure.

4. Methylmercury in Water

Mercury occurs in both surface and ground waters from both natural and anthropogenic sources. The cycling of mercury in surface waters is the basis for the accumulation of methylmercury in fish and will be discussed in several sections of this report. Mercury in ground water has likewise emerged as a public health concern in certain sections of New Jersey.

In lakes, mercury is partitioned between organic particle-bound and dissolved forms. The creation of new water bodies by dams results in the flooding of soil containing natural quantities of mercury and thereby increases the amount of mercury available for biomethylation. Reservoir creation also results in decomposition of flooded organic matter which enhances the rates of methylation. Studies of mercury in NJ lakes show higher mercury levels in fish from newly created than from old or natural lakes (see Chapter 8/Section C). Tree Swallow nestlings living near a reservoir showed a doubling in MeHg body burdens after flooding (Gerrard and St. Louis 2001). However, the toxic effects were to some extent offset by the greater abundance of food in the flooding period.

A drinking water Maximum Contaminant Level (MCL) for MeHg has not been derived (the MCL for total mercury is 2 μg/L). However, if a 2 L/day consumption of drinking water for a 70 kg adult is assumed, the current USEPA Reference Dose for MeHg corresponds to a water concentration of 3.5 μg /l (3.5 ppb). No data are available on the occurrence of MeHg in community drinking water. Recent speciation studies of the mercury contamination in ground water used as domestic drinking water in southern NJ found that up to 8% of the total mercury could be organic mercury. The maximum concentration of organic mercury was 137 ng/l (0.14 ppb) (Murphy et al. 1994). Applying the assumptions described above, this is 4% of the intake corresponding to the Reference Dose for MeHg, or the Hazard Quotient is 0.04 where a hazard quotient of 1 or greater is unacceptable. Drinking water or showering are generally negligible exposure pathways for MeHg.

5. *Summary: Methylmercury in Environmental Media*

Fish consumption is the only significant pathway of environmental human exposure to MeHg. The potential exists for significant exposure through soil ingestion if MeHg per se (or other forms of organic mercury) is discharged directly to the soil. MeHg in soil can also be a significant source of MeHg in aquatic systems. Little attempt has been made to identify MeHg in plants grown on mercury contaminated soil. To date, only trace levels of MeHg have been found in air. Few investigations of the presence of MeHg in drinking water have been undertaken. Data from wells with largely inorganic mercury contamination in NJ show only trace quantities of MeHg.

D. Inorganic Mercury in the Environmental Media

This section covers elemental and ionic forms of mercury. Most studies of mercury in environmental media did not speciate mercury, but report total mercury. In some cases it is possible to infer whether the mercury is organic or inorganic. Most mercury in soil, air, and water is inorganic or elemental, while most mercury in biota is organic.

1. *Inorganic Mercury in Food*

Food chain exposure is mainly important for MeHg, and almost all of the mercury in finfish tissue is MeHg; however, this is not necessarily true for mercury in cereals and other food sources. Although inorganic mercury is present in finfish tissue (as Hg^{++}), inorganic mercury is not significantly bioaccumulated in fish and generally constitutes less than 10% of the total mercury in fish. Inorganic mercury accounts for a higher proportion of the total mercury in crustaceans and mollusks. However, these species tend to have lower levels of total mercury than do finfish. While levels of MeHg in fish are often in the range of 0.1-1.0 ppm for commercial ocean fish and often greater than 1.0 ppm for large freshwater fish and predatory marine fish, the total mercury concentration in mollusks rarely exceeds 0.1 ppm (Stern et al. 1996). The typical levels of total mercury in lobster is reported to be 0.25 ppm (Hall et al.1978), but it is not clear whether this largely represents inorganic mercury, MeHg, or both. In a USFDA Total Diet Study conducted from 1982-1984, 23% of the total mercury was found in the non-seafood portion of the typical diet of adult males 25-30 years old (ATSDR 1999a). This component was most likely inorganic mercury.

Inorganic mercury is taken up to some extent by edible plants (Kabata-Pendias and Pendias 1984). Raw produce in Germany was found to contain total mercury concentrations of 0.005-0.05 μg/g (ppm), but raw mushrooms contained up to 8.8 ppm total mercury (ATSDR 1999a). Based on 1980-1988 UNEP/FAO/WHO data, Galae-Gorchev (1993) estimated that foods other than fish and seafood had average mercury concentrations of 0.01 μg/g, presumably as inorganic mercury.

In individuals who do not consume fish, and who are therefore presumably exposed only to inorganic mercury, the typically low concentrations of mercury in blood and hair indicate that very few are likely to exceed the current USEPA Reference Dose for inorganic mercury (based on mercuric chloride) of 0.3 μg/kg/day.

2. *Inorganic Mercury in Soil*

Inorganic mercury salts (i.e., Hg^{++}) are generally stable in terrestrial soils, and methylation is generally negligible. Interconversion among the various anions or ligands which associate with Hg^{++} however, is possible, with conversion to the sulfide being the most thermodynamically favored conversion, yielding the most stable form (HgS). Given the US EPA Reference Dose for inorganic mercury (as $HgCl_2$) of 0.3 μg/kg/day and assuming that a 15 kg child ingests 200 mg of soil daily, the concentration of inorganic mercury salts in the soil would have to be 22.5 μg/g (22.5 ppm) to exceed the RfD. Background levels of mercury in NJ soils are generally less than 1 ppm, although they may typically be in the range of 1-2 μg/g (ppm) in some urban soils and have been observed as high as 7.7 ppm on golf courses (Fields et al. 1999; see also Chapter 7 of this volume). Hg^{++} concentrations in NJ soils are sometimes found to approach or exceed this level at sites where mercury-containing waste has been discharged. The oral bioavailability of the various Hg^{++} compounds (i.e., the extent to which they are taken up through the gastrointestinal tract and are available for distribution to target sites in the body) varies roughly in proportion to their solubility. Although bioavailability data for inorganic mercury compounds is sparse, it appears that only about 2% of an oral dose of HgS can be absorbed (Stern 1997a). By comparison, for $HgCl_2$, estimates of absorption ranges from less than 7% to about 25% (Stern 1997a). Thus, the levels of Hg^{++} in soil which may actually pose a significant health risk depend to some extent on the specific compound. These values apply to the pure form of the compound. It is likely that when ingested in a soil matrix, the bioavailability is decreased, but few quantitative data on bioavailability in soil are available.

Hg^0 in soil has the potential to volatilize to the surrounding air. Hg^0 vapor released from soil to the outdoor air will tend to dissipate rapidly. However, if released into confined spaces such as into buildings built over Hg^0 contaminated soil, indoor air levels could reach levels of health concern. Exposure to Hg^0 in soil can also occur through ingestion of soil. Because of the tendency of Hg^0 liquid to form globules, it is generally not uniformly distributed among soil particles and determinations of average concentration may differ significantly among samples. Hg^0 is poorly absorbed through the gastrointestinal tract with bioavailability of about 0.01% reported (WHO 1991). Ingestion of Hg^0 in soil is therefore not considered to be a pathway leading to potentially significant exposures.

3. Inorganic Mercury in Air

Hg^{++} is released from combustion sources due to the liberation of existing Hg^{++} in the combusted material, or due to oxidation of Hg^0. Additionally, once airborne, some Hg^{++} is formed by atmospheric oxidation of Hg^0 through oxidation by ozone. Inhalation of inorganic mercury is generally not a significant pathway of exposure. Hg^{++} is subject to removal from the atmosphere by washout during precipitation events and mercury adsorbed to airborne particulates falls out as dry deposition. Deposition on watershed lands or directly to waterbodies by these processes is a major source of mercury transport into aquatic systems where it can become methylated and undergo biomagnification in biota.

Hg^0 in ambient air circulates as part of the global atmospheric mercury budget and is enhanced by localized sources. Ambient air concentrations of Hg^0 are reported to range from about 2 ng/m^3 to about 10 ng/m^3, with the higher end of this range reflecting contributions from specific local sources (ATSDR 1999a). These levels should be contrasted with the current US EPA Reference Concentration for Hg^0 of 3×10^{-4} mg/m^3 (0.3 ug/m^3). Thus, ambient air exposures to Hg^0 are unlikely to pose a significant potential for health risk. In contrast, exposure to Hg^0 vapor indoors as a result of spills or intentional application of liquid

Hg^0 (such as in certain cultural practices) can be significant with respect to health effects. As little as one drop (0.05 ml) of liquid Hg^0 in a sealed bedroom-sized room (assuming a room volume of about 33 m^3 and no air exchange) can result in an air concentration equal to the US EPA Reference Concentration.

Another source of indoor Hg^0 exposure is residential occupancy of buildings in which mercury was previously used in manufacturing. In a former factory in Hoboken, NJ, converted to residential occupancy, air concentrations of Hg^0 ranged from 5-888 $\mu g/m^3$. Two thirds of the residents had elevated mercury in urine (< 20 μg/L). Subtle neurological effects possibly related to this exposure were observed among some residents (Fiedler et al. 1999).

4. *Inorganic Mercury in Water*

Due to the moderate solubility in water of some of the salts of Hg^{++} (e.g., 1 g/35 ml for $HgCl_2$; (ATSDR 1999a), Hg^{++} can occur as a significant contaminant in drinking water either through direct discharge to surface water sources, or through leaching to ground water from contaminated soil. A survey of 6,856 samples of ground water drinking water sources in California found 27 exceedances of the Maximum Contaminant Level of 2µg/l (ATSDR 1999a). In southern New Jersey, compilation of well sampling data from 2,239 private wells in seven counties showed detectable levels of mercury in 59% of the wells (detection limit 0.2-0.5 µg/l), and exceedance of the Maximum Contaminant Level in 306 wells (13.7%) (USGS 1997). Speciation of the mercury in these samples, revealed that $HgCl_2$ accounted for a median fraction of about 94% of the total Hg. Volatile mercury (assumed to be Hg^0) accounted for a median fraction of about 6% of the total Hg. Hg^0 in water is very poorly absorbed through the gastrointestinal tract, but can potentially be inhaled if volatilized from water to indoor air particularly when the water is heated and/or agitated such as in a shower. Estimates of inhalation exposure to Hg^0 volatilized from shower water indicate that if the Hg^0 concentration in water were at the Maximum Contaminant Level and the conditions of use result in 50-100% volatilization of the Hg^0, the inhaled dose from a shower would approach the RfD (Stern 1997b).

5. *Summary: Inorganic Mercury in Environmental Media*

Although it is difficult to identify dietary intake data specific to inorganic Hg, it does not appear that dietary intake approaches the Reference Dose for inorganic mercury in any identifiable group of people in NJ except for those occupationally exposed. Soil highly contaminated with mercury salts may result in exposure above the Reference Dose due to soil ingestion particularly for small children. However, the bioavailability of the various mercury salts varies widely. Ambient air concentrations of inorganic mercury are unlikely to approach levels of health concern. However, very little Hg^0 is required to pose a health hazard under indoor conditions. Inorganic mercury in drinking water has been observed to exceed the Maximum Contaminant Level in some locations. While such contamination is largely due to mercury salts, some Hg^0 has been observed in such cases. Hg^0 volatilized from water during showering may approach levels of health concern under some circumstances.

E. Hair Mercury as a Biomarker of Exposure

Hair has proven to be useful for biomonitoring methylmercury exposure. Hair is a better indicator of methylmercury than of inorganic mercury exposure, and about 80% of the mercury in hair is MeHg (Cernichiari et al. 1995). The more or less constant growth rate of hair (1.1-1.3 cm/month, March et al. 1995), allows the profiling of temporal exposure patterns. For example, in the case of the death of a researcher, Dr. Karen Wetterhahn had accidental exposure to MeHg and the profile of mercury in her hair reached a maximum greater than 900 ppm and declined steadily thereafter, confirming her reported one-time exposure (Nierenberg et al 1998).

Hair thus allows a retrospective approach to estimating the time and magnitude of exposure. People who eat fish less than once a week and have no other mercury exposure generally have hair levels less than 1 ppm. A level of 10 ppm is considered a threshold indication of risk. Women from a fishing community on the coast of northern Peru have hair mercury levels from 1.2-30 ppm (geometric mean 8.3), which was presumably derived from the preponderance of marine fish in the diet (March et al. 1995).

Chapter 3 - ATMOSPHERIC TRANSPORT AND MERCURY DEPOSITION

A. Introduction

Mercury is an especially dynamic pollutant because of its unique physical, chemical, and bioaccumulative properties. The volatility of the liquid elemental metal and some of its compounds, in conjunction with its ability to chemically transform under environmental conditions, makes it easily exchangeable across all environmental media including the biosphere where it can bioaccumulate and biomagnify. After release to the environment, mercury enters into what is referred to as the biogeochemical cycle, where it remains chemically, biologically, and environmentally dynamic for a sustained period of time, until it is ultimately sequestered in stable long-term environmental sinks such as the depths of the ocean, deep freshwater lake sediments, and soil (Fitzgerald et al. 1991). Retiring mercury from commerce, by sequestering it in a secure, permanent storage facility is intended to diminish input to the environment.

This section briefly outlines the many components of mercury fate and transport that influence the patterns of accumulation of mercury in the environment and subsequent exposure. These components are described more thoroughly in the first Mercury Task Force Report (NJDEPE 1993). Direct discharges of mercury to land and water will result in increased mercury in the environment, however this section will focus mainly on the fate and transport of emissions to air.

In the past, direct discharges of mercury to land and water were significant in NJ. One such historic example is the Ventron/Velsicol site which discharged as much as two to four pounds of mercury per day into Berry's Creek (see Chapter 7 of this Volume) up until 1974. These sources are much better regulated today, and it is believed that they now represent a very small portion of the new mercury added to the NJ environment each year. Work is still necessary to prevent mercury that is present on land from reaching water bodies in the state.

B. Emissions

The fate of mercury in the environment begins with emissions to air, land or water. Direct emissions to the air in NJ that result from human activities (anthropogenic emissions) have been studied in detail by this Task Force and are discussed in Volume III, of this report. These emissions come from a wide variety of sources including many types of combustion and the processing of mercury-containing wastes. Mercury from emissions elsewhere also contribute to mercury levels in NJ's atmosphere, and estimating the relative contribution of in-state to out-of-state sources is a challenge.

Globally, natural emissions to air are also a significant source category, contributing as much as 2.5 million kilograms per year (Nriagu 1989). Such emissions result from volcanoes, erosion, seasalt spray, forest fires, and particulate and gaseous organic matter emissions from land and marine plants. Nriagu (1989) estimates that natural sources make up about 41% of the total air emissions in the world, with about 40% of natural emissions coming from volcanoes and 30% emitted by marine plants. Other estimates place natural emissions closer to 20%. The contribution of natural sources in NJ is not known but is likely to be small since 1) the state does not have volcanoes within its boundaries, and 2) most of the coastal zone, where seasalt spray may make a contribution, is on the east or downwind coast.

It has been estimated that anthropogenic activities have increased global atmospheric mercury emissions by at least a factor of 3 relative to natural emissions since the beginning of the Industrial Revolution (Andren and Nriagu 1979).

C. Movement Through Air and Between Air and Land

As mercury is emitted to the atmosphere, it is moved and diluted by local winds. Some may be deposited locally, especially during precipitation events. Eventually the remaining mercury plume merges with the general air mass and becomes part of the global atmospheric pool of mercury. This circulates with prevailing air currents, continually receiving newly emitted mercury and losing it through wet and dry deposition on water surfaces or land. Some mercury that falls on land can run off, through rainfall and erosion, into a local water body. Mercury that reaches water bodies either directly or indirectly can be converted by biota into the more toxic methylmercury, which then biomagnifies up the food chain, where it accumulates reaching high concentrations in some of the longer-lived fish (see Figure 2.2).

D. Atmospheric Chemistry & Residence Times

The form in which mercury is emitted and the occurrence of rain and snow influence whether air emissions will be deposited close to a source or will be transported long distances before being deposited on land or water. If a water-soluble form of mercury (such as mercuric chloride) is emitted, it may be deposited close to the emission source during a precipitation event. If not deposited locally, much of this water-soluble mercury is likely to be washed out of the air within a day or two (as soon as a precipitation event is encountered). Non-soluble forms of mercury (such as elemental mercury) will travel much farther. These forms enter the global reservoir where they are slowly converted to soluble forms of mercury, mainly Hg^{++}, and then washed out. The residence time of non-soluble mercury in the atmosphere is about one year (Mason et al. 1994).

E. Deposition

Two types of mercury deposition occur: wet and dry. Wet deposition (via rain and other types of precipitation) is most efficient at removing divalent mercury (a soluble form) from the air. Dry deposition, via settling and scavenging, is more likely to remove particulate forms of mercury from the ambient air and can also remove gaseous mercury forms.

Whether the deposition is to land or water will define the possible pathways to bioaccumulation. The rate of bioaccumulation is dependent on many characteristics of the receiving water body. For example, the bioaccumulation rate in fresh water lakes will be different from the rate in a moving stream, which in turn is different from bioaccumulation in estuarine or marine waters.

1. Estimates of Wet and Dry Deposition of Mercury

Wet deposition of mercury can be measured directly by placing buckets to collect precipitation on a daily, weekly, or event basis. The water that is collected is then analyzed for total mercury, or occasionally even for specific forms of mercury. Reliable techniques for measuring dry deposition of mercury are not available, so indirect means of extrapolating dry deposition from observations of gaseous and particulate mercury in the air must be used. Algorithms have been developed to calculate the amount of mercury in the air that will deposit on the ground and on vegetation in the absence of rainfall.

When estimates of mercury deposition are needed over a large area, models are sometimes used to generate predicted deposition patterns. Some models are used to predict deposition from a single source or small group of sources within one to 50 kilometers of the point of emission. Other models have been developed to predict the transport and deposition of emissions from many sources over large areas. One such large-scale model (RELMAP) was used by USEPA to describe the impact of emissions throughout the country on wet and dry deposition nationwide (USEPA 1997a).

Models such as RELMAP (Regional Lagrangian Model of Air Pollution) and TEAM (Trace Elements Analysis Model), use a series of mathematical equations to represent the movement of mercury through the atmosphere and from the air to land and water. These models use meteorological data collected at hundreds of airports around the country to describe the dispersion of mercury. They also include a series of equations to describe the chemical reactions that convert mercury from one form to another. Assumptions regarding deposition velocity and scavenging rates (i.e., how fast precipitation can remove mercury from the air) are employed to estimate dry and wet deposition, respectively.

2. *Estimates of Total Deposition in NJ*

At present there are no definitive data that can quantify total wet and dry deposition of mercury in NJ. However, there are modeling and monitoring studies that provide insight into what the deposition is likely to be. These studies include: 1) the Northeast Mercury Study; 2) the Trace Elements Analysis Model; and 3) the NJ Atmospheric Deposition Network. Each of these is described briefly below and the deposition estimates are summarized.

a. Northeast Mercury Study

The Northeast Mercury Study (NESCAUM et al. 1998) includes a modeling analysis of mercury emission sources throughout the country. Using RELMAP, the dispersion of emissions from these sources was predicted for a one-year period using hourly meteorological data from 1989 (e.g. precipitation rates, wind speed and direction). From the predicted concentrations, both wet and dry deposition were estimated at grid squares representing about 1600 square kilometers each (roughly 25 mi x 25 mi).

The model used in this study predicted the total wet and dry deposition rates to be 30 to 100 $\mu g/m^2/yr$ over most of the state of NJ (with a few areas along the coast having predicted rates in the 10 to 30 $\mu g/m^2/yr$ range). When these results are integrated over the whole state (as described below in the discussion of relative contributions), the total deposition is estimated to be 610 to 1740 kg/yr. The Northeast Mercury Study estimates that the relative contribution of wet and dry deposition through the whole Northeastern region (New England, New York and NJ) is about 54% wet and 46% dry.

b. Trace Elements Analysis Model

The model TEAM (Pai et al. 1997) also predicts wet and dry deposition on a national scale. This model uses sophisticated atmospheric chemistry and wet and dry deposition algorithms. The model results (predicted for 10,000 square kilometer grid cells) reported by Pai et al. (1997) are based on 1990 emissions and meteorological data. The model predicts a range of wet and dry deposition rates for NJ, which are summarized below by region. The predicted range for total deposition is 24 to 80 $\mu g/m^2/yr$ (Table 2.2), which is similar to the range of deposition predicted in the Northeast Mercury Study.

Table 2.2. Predictions of Mercury Deposition in NJ from the TEAM Model.

NJ Region	Wet Deposition Rate (μg/m^2/yr)	Dry Deposition Rate (μg/m^2/yr)	Total Deposition Rate (μg/m^2/yr)
North	30-55	26-50	56-80
Central	15-20	8-17	24-32
South	20-30	8-12	24-32

c. NJ Atmospheric Deposition Network

The NJ Atmospheric Deposition Network (NJADN), sponsored in part by NJDEP, is collecting wet deposition and ambient concentration data for a whole suite of pollutants, including mercury, at nine sites around the state. The first site began operating in July 1998. The annual mean wet deposition of mercury, for the four sites in the network measuring wet depostion, is 15 μg/m^2/yr (Eisenreich & Reinfelder 2001). This is higher than the value recorded at most of the sites in the National Atmospheric Deposition Program, which reported wet deposition of mercury with a median value of 9 μg/m^2/yr and a range across 33 sites of 3.9 to 17.7 μg/m^2/yr in 1999 (NADP, 2000). It is also well above the mean wet deposition in the United States and eastern Canada of 10 μg/m^2/yr reported by Sweet et al. (1999), but lower than the wet deposition rates predicted by the two models described above. The difference between observed and predicted deposition is most likely due to a combination of two factors: a) conservative assumptions in the models that tend to result in overpredictions of deposition; and b) decreases in emissions from the timeframes used in the models (1990 for TEAM and 1997 for the Northeast Mercury Study) to the present time which is represented by the recent monitored data. Dry deposition estimates based on gaseous and particulate concentrations of mercury measured in the air are still under review. The mercury results of the NJADN are described in more detail in Chapter 7 of this Volume.

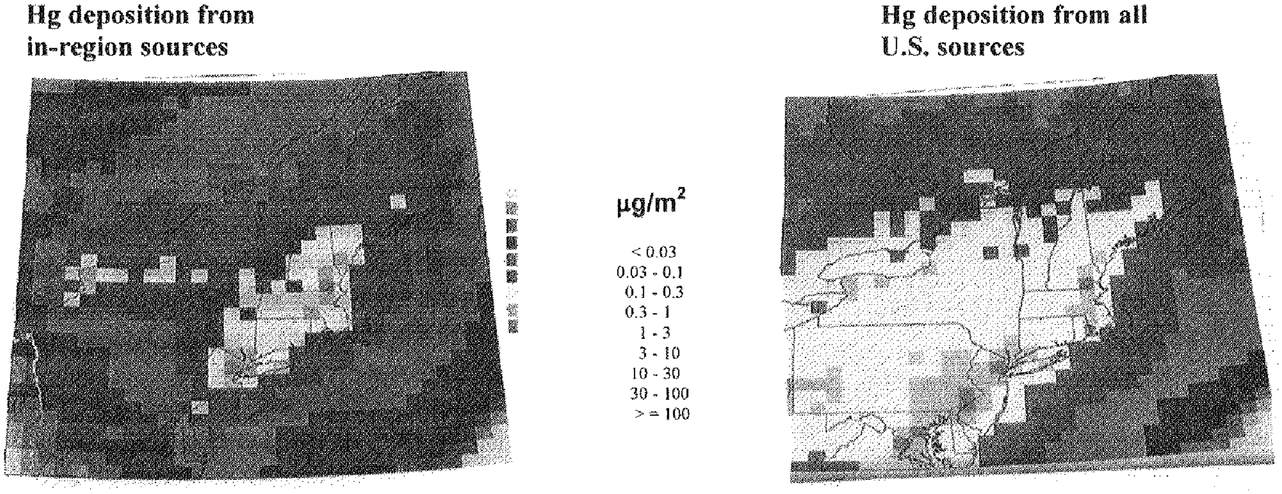
3. Relative Contributions of In-State and Out-of-State Emissions to Deposition in NJ

The Northeast Mercury Study (NESCAUM et al. 1998) provides some rough estimates of the relative contribution of in-state mercury emissions and out-of-state mercury emissions to total mercury deposition in NJ. The study reports the results of three model runs which included: 1) only sources located in the eight northeast states; 2) all other sources in the Unites States; and 3) only the global reservoir of mercury which is present throughout the world. These results are presented in a series of maps which show a range of wet and dry deposition for each grid cell in the region. (A grid cell is about 1600 square kilometers. The total area of NJ is about 21,700 square kilometers.) These results are summarized in Table 2.3.

The deposition estimates for the sources located in the eight Northeast States can be taken as a good representation of deposition in the state from NJ sources alone since this state is generally at the upwind edge of the region. Some of the deposition in the Northeastern grid cells may be influenced by emissions from sources in New York state; however, the impact of other northeast state sources in NJ should be rather slight in this model run. These model predictions (as presented in Figure 2.3, from NESCAUM et al. 1998) can be used to get a rough estimate of total deposition by summing across grid cells the product of the deposition rate (μg/m^2/yr) and the grid area (km^2). This calculation results in the values in the last column of Table 2.3. This estimated total deposition integrated over the whole state is about

610 to 1740 kg/year. This calculation indicates that the in-state sources could contribute about one-third of the total mercury deposition in the state.

Figure 2.3. Estimated Total Mercury Deposition in the Northeast from In-Region Sources and from All U.S. Sources.



Hg deposition from in-region sources

Hg deposition from all U.S. sources

Source: NESCAUM et al. Northeast States and Eastern Canadian Premiers Mercury Study - A Framework for Action. February 1998)

Table 2.3. Deposition Results Reported in the Northeast Mercury Study (NESCAUM et al. 1998).

Source of Mercury Emissions	**Range of Wet & Dry Deposition Rates in NJ**	**Estimated Total Deposition Integrated over NJ**
Sources Located in the 8 Northeast States	South: 3-10 µg/m^2 Northwest: 10-30 µg/m^2 Camden: 10-30 µg/m^2 Northeast: 30-100 µg/m^2*	200 – 650 kg/yr
US Sources Located Outside the 8 Northeast States	Southwest: 30-100+ µg/m^2 All other grids: 10-30 µg/m^2	340 – 870 kg/yr
Global Reservoir	Entire State: 3-10 µg/m^2	70 – 220 kg/yr
All Sources Combined	Some Coastal Grids: 10-30 µg/m^2 NE and SW Metro Areas: >100 µg/m^2 All other Grids: 30-100 µg/m^2	610 – 1740 kg/yr

* One grid cell shows deposition greater than 100 µg/m^2. This estimate was most likely influenced by two NJ sources which were modeled but are no longer in existence, so this result is not included in the table. Instead, it is assumed that the maximum deposition in this grid cell was 100 µg/m^2.

4. Uncertainty in deposition estimates

Many uncertainties make it difficult to assess the wet and dry deposition of mercury, either through monitoring of actual values or modeling of the transport and fate of mercury emissions to the ambient air. However, it is important to note that despite all of this uncertainty, comparisons between modeling and monitoring in many studies (including Pai et al. 1997 and NESCAUM et al. 1998) show a strong correlation between predicted and observed wet deposition rates.

Methods for measuring wet deposition of mercury are limited in their ability to characterize the spatial and temporal distribution of deposition by the investment and maintenance of sampling stations and the cost of analysis. Estimates of dry deposition are even more uncertain because they are extrapolated from air concentrations using various assumptions regarding deposition velocity for the various forms of mercury.

Models of mercury transport begin with a mercury emissions inventory which identifies, estimates and catalogues the mercury emitted from various source types. The quantity of mercury emissions, the location of the emissions, and the chemical form of the mercury when it is emitted are all sources of uncertainty. Although substantial progress has been made in identifying the quantity and location of mercury emissions, there is still a great deal of work to be done in identifying the chemical form. Knowledge of the speciation is especially critical when predicting wet and dry deposition rates since they vary from one species to another. Mercuric chloride, for example, is much more water soluble than elemental mercury and, therefore, is more likely to be absorbed by rainwater and to be deposited close to its source.

Seigneur et al. (1999) have carried out an extensive analysis of the uncertainties associated with model predictions of human exposure to mercury through the consumption of fish. This analysis considered three prediction tools that must be used together to make such estimates of mercury ingestion. These tools are: a) the atmospheric transport and fate model; b) the watershed and biota bioaccumulation model; and c) the model of fish consumption patterns. The atmospheric transport and fate model variables included in their uncertainty analysis were mercury emission speciation, ozone atmospheric concentration, atmospheric precipitation, mercury atmospheric background concentration, mercury deposition velocity, and cloud water pH. Of these variables, mercury emission speciation contributed the most to the model uncertainty.

5. Summary: Transport and Deposition

Some mercury, particularly mercury that is emitted as soluble mercury or as particulates, deposits locally. The remaining mercury eventually enters the global atmospheric pool of mercury. The residence time of non-soluble mercury in the atmospheric is about one year. Eventually atmospheric mercury deposits on surfaces from which it can be transported directly to water bodies.

Total deposition rates for mercury in NJ have been predicted in the Northeast Mercury Study to be on the order of 10 to 100 $\mu g/m^2/yr$ and in the TEAM Study to be about 24 to 80 $\mu g/m^2/yr$. These two studies give comparable total deposition rates. The wet deposition rates observed by the NJADN are on the order of 15 $\mu g/m^2/yr$. This is on the lower end of the wet deposition range predicted by TEAM (15 to 55 $\mu g/m^2/yr$). The Northeast Mercury Study does not break out wet deposition for NJ alone, but it does estimate the relative contribution of wet to dry deposition for the region to be about 46% dry and 54% wet. Using this ratio would give a NJ wet deposition rate of 5 to 54 $\mu g/m^2/yr$, which is about the same range as TEAM and includes the NJADN rate within its bounds. It has been estimated that the NJ emissions account for about one-third of the mercury which deposits in NJ.

F. Recommendations

Maintain and enhance a long-term air deposition monitoring system that incorporates state-of-the-art detection limits and speciation to document temporal and spatial trends in mercury deposition (Recommendation "L" in Volume 1).

Information regarding deposition of mercury in NJ is still quite limited. Both modeling and monitoring approaches should be pursued to fill this gap. The information gathered in this way can be used to assess the current status of deposition in the state and to follow trends as emission reduction programs are put into place. These tools might also be used to provide a rough estimate of the portion of deposition attributable to in-state sources and to out-of-state sources. Recommendations regarding the development of these tools follow.

Air Monitoring: Long-term air deposition monitoring sites should be established in NJ. Some of the sites may be the same as those currently in the NJ Air Deposition Network that is operated by Rutgers and funded, in part, by NJDEP. Site locations should be selected so that deposition of mercury emitted out-of-state can be distinguished from mercury emitted in the state. Sampling frequency for particulate mercury may be every 12th day at some of the sites, but a subset should be enhanced to collect particulate mercury data every 6th day. Weekly samples of wet deposition should be collected.

Deposition: The Department should have access to a state-level version of the EPA model for fate and transport (RELMAP) that can be run using the up-to-date emissions inventory that has been developed by the Mercury Task Force. The results of this modeling effort, combined with new EPA model results for the whole country, thus will provide a better estimate of the relative contribution of in-state and out-of-state sources and can be used in subsequent years to predict the local benefit of reduction strategies.

Since the air emissions of mercury in NJ do not appear to account for the majority of the mercury deposition in the state, it is very important that the NJDEP continue to press for national mercury emission reduction programs.

Chapter 4 - EXPOSURE TO MERCURY

A. Introduction

Nationally, the most important source of exposure to any mercury compound is the consumption of fish. Certain populations may have occupational exposures and in certain areas of NJ consumption of water from private wells can be a significant source of mercury exposure (see Volume II Chapter 7). The extent of exposure to mercury from cultural uses is not known and such practices appear to be limited to specific communities. There has been a long history of occupational exposure to mercury, but nationally most significant occupational exposures have ended. While dental amalgams may be a significant source of exposure on an individual bases, the health implications of such exposures are unclear. This chapter therefore will largely emphasize exposure to methylmercury from fish consumption.

B. Mercury in Fish

1. Introduction

Mercury in fish was already recognized as a public health and ecological problem in the 1960's. It was commonly assumed that local point sources (industrial effluent, utility emissions, fungicide applications) were the main sources, and many studies focused on waters with nearby point source contamination. By the early 1980's there was convincing evidence of mercury contamination of water bodies remote from point sources of mercury emissions or effluent, calling attention to regional and global atmospheric deposition as the source of elevated mercury levels.

There is a huge amount of literature on mercury levels in fish from Eurasia and North America, much of it in peer reviewed journals but even more in the gray literature (e.g., agency reports; see references in Johnston et al. 1991) and more recently in unpublished data bases. The Concentration Factor (CF) (for higher trophic level fish vs. water) can be in the range of 10^5-10^6 (USEPA 1997e). The typical assumption is a one million-fold CF.

MeHg bioamplifies through aquatic food chains, and consumption of fish is the most important pathway for human exposure to MeHg. Most of the literature on Hg in fish reports only total Hg, but in most cases where the proportion of MeHg/total Hg has been measured in fish, MeHg comprises 90% or more of the total Hg. Most fish eaten by most people in the United States are purchased in supermarkets or fish stores (commercial fish), but recreational fishing is extremely popular and many anglers consume at least some of the fish they catch. A small percentage of the population relies on self-caught fish for a significant portion of their diet (subsistence fishing). The distinction between recreational and subsistence fishing is sometimes blurred (Burger et al. 2001b).

Gold mining practices throughout the developing world have resulted in increased exposure to elemental mercury (primarily occupational) and to methylmercury (e.g. de Jesus et al. 2001) in fish. Many South American tribes live along waterways and fish play important roles in their diets. Predatory fish have higher mercury levels than omnivorous or herbivorous species (Lacerda et al. 1994). In Rondonia, Brazil, sediment mercury levels were as high as 20 ppm, and levels in fish were up to 2.7 ppm (Pfeiffer et al. 1989). In French Guiana, 57% of tribal members had hair levels above 10 ppm and 14.5% of the fish exceeded 0.5 mg/kg. Amazonian Indians in two villages along the Rio Tapajos averaged about 25 ppm mercury in hair (maximum 151 ppm), while the average level in fish was 0.69

ppm (Malm et al. 1995). Even in North America where Indian tribes consume large quantities of fish, they may exceed tolerable daily intake levels (Marien and Patrick 2001).

2. *Factors Influencing Mercury Levels in Fish*

Factors influencing mercury levels can be divided into exogenous (characteristics of the waterbody) and endogenous (characteristic of the individuals or species). Exogenous factors include pH, sulfur and organic matter (e.g., dissolved organic carbon). Endogenous factors include species, habitat and food preferences, metabolic rate, age, growth rate, size, mass, and diet, (Jackson 1991).

Many studies have shown that concentrations of Hg in fish tend to be higher at low pH (Grieb et al. 1990; Cope et al. 1990), although acidity explained only a small portion of the Hg variability in some Russian lakes (Haines et al. 1995) and a high amount of variability ($r = -0.93$) in others (Haines et al. 1992). Yellow Perch had higher mercury levels in Wisconsin lakes with lower pH, and the Hg in Walleyes was positively correlated across lakes with the Hg in perch, their favored prey (Cope et al. 1990). Organic matter experimentally increases mercury accumulation in Yellow Perch (Johnston et al. 1991).

The mechanism(s) of the interaction---presumably an influence on uptake more than on methylation per se (Miller and Akagi, 1979) ---is still not clear at this time. At low pH, the formation of the MeHgCl rather than the MeHgOH is favored and this species is more readily absorbed by plankton. Acid Neutralizing Capacity of different lakes was also negatively correlated with Hg in Yellow Perch muscle from those lakes (Grieb et al. 1990).

Numerous studies have shown that within a species the larger, longer, and older fish have higher concentrations of mercury. However, the relationship varies among species. Faster growing species tend to have a flatter relationship due to a faster assimilation into tissue than accumulation of mercury (Huckabee et al. 1979).

Bache et al. (1971) characterized the increasing total Hg and MeHg in Lake Trout as a function of age. Mercury is positively correlated with age, length, weight of Yellow Perch (Grieb et al. 1990), but it increased more strongly with age in Northern Pike, White Sucker and Largemouth Bass (Grieb et al. 1990). Hg in liver and muscle but not gill tissue was positively correlated with fish size in Largemouth Bass (Jagoe et al. 1996).

3. *Levels of Mercury in Commercial Fish*

In the early 1970's a comprehensive database of mercury levels in 204 species of commercial finfish, mollusks, and crustaceans landed in the US was established by the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration, US Department of Commerce based on sampling of species intended for human consumption (Hall et al. 1978). Fish landed in foreign ports and transported to the US market were not represented. The number of individual fish sampled varied by species, but most species were represented by more than 10 samples. Total mercury concentrations were reported in range categories. In muscle tissue (the most commonly consumed part of fish) the highest observed Hg concentration was in the 4-5 ppm range. In finfish liver however, the highest observed mercury concentration was in the 10-20 ppm range. Of the catch intended for human consumption, 48% had mercury concentrations below 0.1 ppm, 41% had concentrations of 0.1-0.2 ppm and 11% had concentrations greater than 0.2 ppm. Tuna, the most commonly consumed fish, (muscle of various species) had concentrations ranging from 0.1 to 0.4 ppm.

Shrimp (various species) had concentrations ranging from less than 0.1 ppm to 0.2 ppm. Salmon (muscle of various species) had concentrations less than 0.1 ppm. Flounder (muscle of various species) had concentrations ranging from less than 0.1 ppm to 0.2 ppm (Hall et al.1978).

The overall average concentration (weighting the concentration mid-point for each concentration category by the percentage of the total catch intended for human consumption represented by that category) was 0.11 ppm. Among those species with the most highly elevated mercury levels, shark (muscle of various species) had concentrations ranging from 0.5 to 2.0 ppm and tilefish was in the range of 1.0-2.0 ppm. No data were reported for swordfish, a species which typically has high mercury concentrations. All of the above results are for total mercury and it is reasonable to assume that about least 90% of the amount was MeHg.

No comprehensive study of mercury in commercial fish has been reported since the NMFS study of the 1970's. This is a serious problem since there have been significant changes in fisheries due to overfishing. Fishing grounds have shifted, the species composition has changed, and the average sizes of fish are smaller. At the same time industrial point source releases have been reduced while air emissions from utilities have increased. Thus, the levels today could be different from levels of the 1970's. The USFDA did report on methylmercury concentrations in a smaller scale sampling of selected species (USFDA 1992). These samples did not represent the overall catch intended for human consumption, and many species are represented by a small number of individuals. However, this database does contain results from 99 samples of Swordfish revealing a mean MeHg concentration of 0.93 ppm. When the NMFS and FDA databases are compared for the 15 species for which at least three samples were reported in each database, the mercury concentrations in the FDA database are lower than that reported in the NMFS database for all but two species (shrimp and oysters). The mean ratio (FDA/NMFS) is 0.66 and the difference is statistically significant. There are several possible explanations for this difference. They include: data from 1970 was for total mercury and 1992 data was for methylmercury; species misclassification; reduction in average size of fish within a species; inter-laboratory variability; improvement in analytic technique with lowering of detection levels; and actual decline in mercury pollution.

Although all of these factors may contribute to the apparent decline, one of the most important differences is that in the approximately 20 years separating these databases, there has been widespread commercial over-fishing which has resulted in the landing of smaller and younger fish. For any given species, smaller fish tend to have lower Hg concentrations than larger ones.

In 1991, the USFDA conducted a survey of mercury levels in canned tuna from 18 FDA districts throughout the US (Yess 1993). Samples from 220 cans representing a selection of packing liquids, styles (e.g., chunk light, solid white, etc.), and can sizes were analyzed for MeHg. Although no formal statistical procedure was followed, the data appear to roughly reflect the availability and prevalence of the various choices. The mean MeHg concentration was 0.17 ppm (ranging from below 0.1 up to 0.75 ppm, with a 90th percentile concentration of 0.42 ppm). Of the various styles, chunk white had the highest average concentration (0.31 ppm), while chunk and chunk light had the lowest (0.10 ppm).

Given the existence of only two incomplete data bases and the lack of any systematic program for fish surveillance, the Task Force concludes that there is a serious lack of current data on Hg levels in commercial fish nationally and locally. Accurate characterization of exposure and risk from MeHg intake, as well as appropriate consumption guidance, requires the systematic and regular collection of such data.

4. Levels of Mercury in Non-Commercial Fish

Fishing is one of the most popular outdoor recreational activities in the United States. The number of licensed fishermen in NJ is approximately 250,000, and since salt water fishermen need no license, it is conservative to estimate that 15% of the NJ population fish at least occasionally. Not only do fishermen eat more fish more often than the average member of the general public, but they often eat species that are usually not available commercially. Since this subset of the population consumes so much fish, it is likely to be at higher risk from any contaminants in the fish. Hence it is important to document mercury levels in sport fish. Subsistence fishermen likewise consume large amounts of fish, mostly species that are not commercially available. Even people who do not fish may receive and consume fish from friends and family members.

There are many papers and reports on Hg levels in fish. Studies differ widely in the number of water bodies, the number of species, and the number of individuals sampled. Many studies, particularly early studies, relied on pooled samples to provide cost-efficient statistical validity, at the expense of fully characterizing the statistical distribution of mercury in the sample. More recent studies have been more likely to analyze individual fish, as the instrumentation has improved.

Studies focused on risk to humans usually analyzed muscle or edible fillets. Research focused on risks to the fish themselves frequently analyzed liver, and sometimes kidneys, gills, or other tissue. Less frequently, whole fish would be analyzed to provide information on the accumulation of mercury up the food chain. Usually only small fish at lower trophic levels would be analyzed in their entirety.

Studies differ also in the parameters reported: arithmetic mean, geometric mean, median with or without percentiles, range and some studies report on a dry weight rather than wet weight basis. One of the most useful values, however, is seldom reported---the percent of fish of each species (and perhaps of each size or age class) that exceed specific mercury criteria (usually 0.5 or 1 ppm). The likelihood of excess exposure can be influenced by the proportion of fish exceeding the criterion, and the likelihood that such fish would be caught and eaten. If only 1 percent of fish exceed a level, one can be confident that the next fish meal will comprise low mercury fish.

For example, Gerstenberger et al. (1993) report the number of Walleye in the ranges of 0.5 to 0.74, 0.75-1.00 and greater than 1.00 ppm. Of 83 fish in 34 Wisconsin lakes, the grand mean mercury was 0.52 ppm, with individual lake means ranging from 0.29 to 1.0 ppm. In the lake with the highest mercury, two of three fish exceeded 1 ppm and, overall, 47% of the fish exceeded 0.5 ppm and 7% exceeded 1.0 ppm.

In 1984 and 1985, US Fish and Wildlife Service (USFWS) identified mercury concentrations in predatory fish species (e.g., trout, Walleye, Largemouth Bass) that were at nearly twice the level in bottom dwelling species (e.g., carp, catfish and suckers). EPA's National Study of Chemical Residues in Fish (NSCRF) study found the mean mercury concentration in bottom feeding fish species to be generally lower than the concentrations found in top level predatory species. In addition, the study revealed that the majority of the higher mercury concentrations identified were in fish collected from the northeastern states. A 1998 NESCAUM report on mercury concentration in fish collected from northeastern states and eastern Canadian provinces found that the top level sport fish species, such as Walleye, Chain Pickerel, Largemouth Bass and Smallmouth Bass typically exhibited the highest mercury concentrations. Highest mercury concentrations were identified in a Largemouth Bass (8.94 ppm) and Smallmouth Bass (5.0 ppm).

The EPA's 2001 report, National Listing of Fish and Wildlife Advisories collected from 43 states provides a national mean mercury concentration for several predator and bottom feeding fish species. The national mean mercury concentrations for walleye, Largemouth Bass, Smallmouth Bass and Brown Trout are 0.52, 0.46, 0.34 and 0.14 ppm (wet weight) and 0.11, 0.11, and 0.09 ppm (wet weight) for Carp, White Sucker and Channel Catfish respectively.

In 1993, the US EPA, Office of Water generated a National Fish Tissue Data Repository (NFTDR). The NFTDR stores fish and shellfish tissue contaminants data submitted by state and federal agencies to EPA's Ocean Data Evaluation System (ODES). This system provides a means of retrieving, downloading and analyzing data stored from this system. Data for non-commercial fish species are available for every state. Table 2.4 summarizes mercury contaminant data for several popular freshwater gamefish species.

In January 2001, EPA released a new surface water criterion value for methylmercury. Whereas traditionally surface water criteria are based on analytic measurements of contaminants in water, this new criterion is based on the concentration of MeHg in fish tissue, due to the strong bioaccumulative tendency of MeHg in aquatic ecosystems. As a general rule of thumb, the ratio of MeHg in fish to MeHg in the same water column is about 1 million to 1. This criterion value of 0.3 μg/g (ppm wet

weight) is intended to protect human health. EPA expects the criterion to be used as guidance by states in updating water quality standards and in issuing fish and shellfish consumption advisories.

Table 2.4. Mercury Concentrations in Selected Fish (EPA/NFTDR 1993).

Species	State	Samp.	Range	Mean	Highest Lake
Chain Pickerel	North Carolina	50	0.02-1.90	0.5	White Marsh Lake
	Vermont	2	0.35-0.65	0.5	Lake Groton
	New Hampshire	22	0.13-0.84	0.38	Conway Lake
	Arkansas	1	-	1.17	Big Johnson Lake
	South Carolina	1	-	0.76	Flat Rock Pond
	Alabama	1	-	0.59	Little Escambia Creek
	Rhode Island	15	0.01-0.88	0.49	Yawgoo Pond
Largemouth Bass	Minnesota	17	.09-1.40	0.46	Orchard Lake & Pelican Lake
	Mississippi	1	-	1.21	Leaf River
Bluegill Sunfish	Wisconsin	205	0.02-0.58	0.13	Waccaman River
	Oregon	23	0.01-1.13	0.35	Cottage Grove Res.
	Kentucky	18	0.14-0.50	0.28	West Kentucky Lake
	Georgia	3	0.30-0.80	0.53	Satilla River
Yellow Bullhead	Maryland	1	-	0.11	
	Wisconsin	7	0.02-0.20	0.09	Henry Lake
	Arizona	6	0.34-0.89	0.52	Pena Blanca Lake

	South Carolina	2	0.44-0.49	0.47	Four Hole Swamp
	Ohio	7	0.06-0.41	0.23	Tuscarawas River
	Massachusetts	17	0.25-0.58	0.36	Upper Naukeg Pond
	Michigan	8	0.42-0.90	0.62	Selkirk Lake
	Minnesota	10	0.09-0.63	0.26	Bush Lake
Brown Bullhead	North Carolina	35	0.02-0.49	0.12	Big Creek
	New Hampshire	22	0.05-0.59	0.18	Monomomac Lake
	South Carolina	4	0.25-0.26	0.25	Langley Lake
	Ohio	4	0.03-0.12	0.07	Pine Creek
	Georgia	2	0.10-0.10	0.1	Ocmulgee Lake
	Oregon	8	0.45-0.71	0.56	Cottage Grove Res.
	New York	6	0.01-0.18	0.07	Moreau Lake
	Massachussetts	168	0.04-0.53	0.14	Wampanoaq Pond
	Michigan	27	0.05-0.67	0.24	Sisters Lake
	Rhode Island	12	0.04-0.31	0.1	Tioque Lake
	Minnesota	5	0.02-0.08	0.05	Winnibioshih Lake

Data on individual specimens, skin-on fillet, except for samples of bullhead (skin-off fillet)
Data reported in µg/g (parts per million) wet weight concentrations

5. *Patterns of Fish Consumption and Advisories*

The greatest number of fish consumption advisories issued by state agencies throughout the country are for mercury in recreational species of fish. EPA reports that almost 79 % of all the fish contaminant advisories issued were at least partly due to mercury and that the number of states issuing mercury-related advisories has steadily increased in recent years. In 1993, a total of 899 mercury advisories had been issued by 27 states. In 2000, a total of 2,242 fish consumption advisories for mercury were issued by 47 states. The increase in mercury advisories is largely attributed to an increased awareness of mercury impacts in the aquatic environment and an increase in fish monitoring programs throughout the states.

The amount of fish that people consume varies greatly from place to place and time to time. Fish consumption has increased in the United States over the past 50 years (Anderson and Rice 1993), partly due to health education messages and partly due to the increased availability of fresh and frozen fish in markets. In some countries (e.g., Japan, Seychelles) and some regions (Amazonian rivers), fish consumption rates are much higher on average than in the United States, however, even in the United States some people consume great quantities of fish (e.g., Burger et al. 1998). In a South Carolina study, for example, black fishermen averaged more than twice the fish consumption of white fishermen along the same river stretch (Burger et al. 2001). Understanding the statistical distribution of fish consumption is therefore important for risk assessment, regardless of whether the fish consumption is influenced by ethnicity, health considerations, or personal preferences.

Data on fish consumption patterns in NJ are provided in Chapter 9, Section B. These include stratified studies of New Jerseyans, a study of pregnant women, and several interview studies of fisherfolk.

Attempts to estimate fish consumption are subject to uncertainties (see discussion in Jacobs et al. 1998). Price et al. (1994) argued that "creel surveys" oversample frequent anglers and therefore overestimate the average fish consumption. They argued that instead of the EPA Guidance value of 30 g/day for anglers, a value of 2 g/day was more representative. Using random-digit dialing, Stern et al. (1996) estimated that New Jerseyans had a mean fish consumption of 50 g/day and Burger et al. (1998) found a similar value (51 g/day) for fisherfolk in the NY-NJ Harbor.

Indeed, based on extensive interviews of fishermen along the Savannah River in South Carolina, Burger et al. (1999) reported that the EPA's criterion of 19 kg/year for recreational fishers was inadequate for estimating risk to high end consumers. They reported that fish consumption was 17.6 kg/year, but about half of the black fishers and about 30% of whites exceeded 19 kg/year, and 25% of blacks and 5% of whites exceeded the EPA's "subsistence" criterion of 50 kg/year with a maximum of over 100 kg/year. Median consumption rates were 51.8 and 35.2 g/day for black males and females, and 18.8 and 12.8 g/day for white males and females (Burger et al. 2001). The Hazard Quotient for mercury effects exceeded one for black males eating Bowfin and Largemouth Bass (median consumption) or most species (75th percentile of 131 g/day) consumption. White males consuming Bowfin and Bass at the 75th percentile (53.4 g/day) also exceeded an HQ of 1.0 (Burger et al. 2001).

6. Summary and Conclusions: Mercury in Fish

Nationwide, it appears that nearly all adults and most children eat at least some fish. The average fish consumer eats 1-3 fish meals per week (including canned tuna), but a significant fraction of the population eats five or more meals per week. The consumption by women of childbearing age is generally comparable to or lower than that of the general population. The frequency of consumption appears to have increased significantly since the 1970's, although lack of comparability of survey methods makes precise comparisons to recent trends difficult. Tuna and shrimp account for about half of the total fish consumption.

Based on data from the early 1970's, the average Hg concentration in muscle tissue in commercial fish in the US intended for human consumption was 0.11 ppm, and the most commonly consumed species generally had levels in the 0.1-0.2 ppm range. Tuna are generally in the range of 0.1-0.4 ppm. Higher trophic level fish often exceed 1 ppm. More recent data suggest that mercury levels in commercial fish may have declined over the past 20 years, perhaps reflecting reductions in industrial uses and releases of mercury or changes in size of fish harvested. Nonetheless, elevated levels of mercury are still found in commercial fish, commonly exceeding 1.0 ppm. The lack of regular and systematic sampling of commercial fish is a serious impediment to assessing and communicating the risk to fish consumers.

Mercury has been shown to enter the aquatic food chain very rapidly, and is readily bioaccumulated to elevated levels in many recreational sport fish. Fish at the top of the food chain, which are typically gamefish species, can bioaccumulate mercury to levels a million times greater than the mercury found in the surrounding water.

C. Other Sources of Exposure

1. Occupational Exposures to Mercury

A special exposure pathway involves occupational exposure, primarily through inhalation of elemental mercury. Mercury has had many industrial uses, for example in thermometers and electronic equipment, in batteries, as a liquid seal in vacuum pumps and gas regulators, as pigments, in amalgamation, and in biocides. Biocidal uses include common antiseptic agents, vaccine preservatives, anti-fouling paint, and fungicides (particularly for seed dressings). Many of these uses have been greatly curtailed.

The main occupations in which exposure has been documented include mining, smelting, precious metal extraction by amalgamation, instrument manufacture, gilding using gold-mercury amalgam, manufacture of drugs and health products containing mercury, felting of fur, finger-printing with a mercury-chalk mixture, and dental work. The Renaissance alchemist and one of the fathers of toxicology, Paracelsus, described mercury poisoning in miners of quicksilver (liquid elemental mercury) in Idria, Yugoslavia in the 1550s (Hunter 1974). Ramazzini, the father of occupational medicine, wrote: "It is from mercury mines that there issues the most cruel bane of all that deals death and destruction to miners." (Ramazzini 1713). Ramazzini (1713) described the maladies of gilders exposed to mercury, "Very few of them reach old age, and even when they do not die young their health is so terribly undermined that they pray for death".

The biocidal properties of mercury were commonly exploited in anti-fouling paints for ship bottoms, but, except for naval vessels, this use has been replaced mainly by tributyltin, which is itself highly toxic to aquatic organisms. Mercury biocides are organic compounds that pose a risk to production workers and applicators. Mercury mining has caused frank mercury poisoning among miners. The fabrication, use, and disposal of mercurial products is also an important source of exposure. Dentists and technicians are highly exposed to mercury used in amalgam fillings which continue to be in widespread use as a dental restorative, although an increasing number of dentists are using other materials. Fulminate of mercury has been important as an explosive. Use of mercury in manufacturing thermometers has frequently been a source of elevated exposure. Mercury was most familiar as the indicator liquid in thermometers and barometers. Mercury vapor lamps, mercury switches, and mercury batteries were also widely manufactured and installed. Now spills of mercury from thermometer breakage or during replacement of gas meters have become a commonly recognized residential source of elemental mercury exposure. Mercury sulfide has been widely used as a red pigment, and mercurials were added to paints to cut down on mold.

The potent toxic properties of mercury resulted in several different medicinal uses. Physicians treated syphilis by rubbing liquid mercury into the skin of patients. The efficacy was dubious but the toxicity was certain, and the doctors suffered from the repeated exposure to mercury (Ramazzini, 1713). Likewise Ramazzini (1713) described the plight of mirror makers who learn "how malignant is mercury....Those who make mirrors become palsied and asthmatic from handling mercury....gazing with reluctance and scowling at the reflection of their own sufferings in their mirrors and cursing the trade they have adopted".

Alice Hamilton (1925), the founder of modern occupational medicine, described mercury poisoning in New Almaden, California, including sore mouth and gums, nervousness, irritability, insomnia and depression. During extraction of mercury from ore, workers experienced severe gum disease and loss of teeth, as well as the characteristic tremor. The Mad Hatter syndrome, made famous in Lewis Caroll's "Alice in Wonderland", was a manifestation of the mercury used as a corrosive in the manufacture of felt hats (Hunter 1974).

Although the vast majority of occupational exposure involves elemental or inorganic mercury, there is and has been significant exposure to organic forms, particularly in the manufacture, fabrication, and application of mercurial fungicides and additives to anti-fouling marine paints. Organomercurials have had many biocidal uses, particularly as fungicides in agriculture. They have been used as antiseptics (e.g., mercurochrome, merthiolate) and as a preservative for vaccines and pharmaceuticals. These latter uses have been reduced. These compounds are highly toxic by the dermal route as well as by inhalation and incidental ingestion. Hunter (1974) describes many scenarios of death and morbidity in workers exposed to organomercurials during manufacture, storage, or application.

The widely accepted standard of 50 $\mu g/m^3$ in workplace air is intended to protect workers exposed for a 40-hour work week over a 40-year working lifetime. The National Institute for Occupational Safety and Health recommended a standard of 25 $\mu g/m^3$, and the American Conference of Governmental Industrial Hygienists (ACGIH) lowered its TLV to 25 $\mu g/m^3$. In the past, workplace levels have been reported to be much higher, and Bidstrup et al. (1951) reported levels of 1700 $\mu g/m^3$.

The newest group of exposed workers are those involved in the cleanup of mercury spills, the recycling of mercury products, and the remediation of hazardous waste sites containing mercury. Ideally, modern protective methods and industrial hygiene will prevent any significant exposure to such groups. However, in some cases huge quantities of mercury are encountered, such as the 260,000 pounds of mercury recently retrieved from the Holtra Chem chloralkalai plant which closed in Maine in 2000.

In the United States, most of the above mentioned uses ended long ago, while others such as the use of mercury in gas regulators, thermostats, and thermometers is just now being phased out. Mercury continues to be used in fluorescent and mercury vapor lamps. Mercury in batteries was greatly reduced during the 1990's. Increased awareness of the potential for exposure and health effects appears to be resulting in a decrease in exposure through industrial hygiene controls (ATSDR 1999a).

2. *Dental Amalgams*

Dental amalgams continue to be the most commonly used restorative material in dentistry in the United States. They typically contain about 50% elemental Hg (Hg^0) by weight (USEPA, 1997b). There is a lively controversy regarding the possible importance of dental amalgams as a source of mercury in people, and whether this source, measured in μg/day, is sufficient to prevent various diseases in sensitive individuals. The Task Force was not charged with investigating this controversy but applauds efforts to reduce this use and encourages the use of suitable substitute materials and preventive measures. Moreover, insurance policies that do not adequately pay for alternative restoratives create an unfortunate incentive for continued use of mercury and should be changed.

The use of mercury in dentistry continues to be a potential hazard for dental personnel, and the release of mercury from dental offices into the environment is covered extensively in Volume III of this report.

3. *Thimerosal in Vaccines*

The organomercurial, Thimerosal, commonly used as an antiseptic (merthiolate) has been used for decades to stabilize vaccines. Recent concern over whether the dose of organic mercury from vaccines might cause neurological conditions (for example, autism) in some sensitive individuals receiving vaccines in the neonatal period (particularly low birth weight premature infants), has led the Food and Drug Administration to require the elimination of Thimerosal as a preservative in biologics intended for infants. The Task Force did not independently investigate this issue since the decision had already been reached by the FDA. Calculations indicated that the total amount of mercury that could be re-circulated into the environment by this route was negligible.

D. Recommendations

Expand and institutionalize routine monitoring for mercury in fish from NJ waters through State-level programs (From Recommendation "G" in Volume 1).

Actively encourage the federal government to initiate and maintain comprehensive monitoring and surveillance for mercury in commercial fish and to require that information regarding the mercury content of fish be made readily available. If the federal government does not initiate nation-wide evaluation of commercial fish, NJ should, with other states in the region, monitor mercury in commercial fish (From Recommendation "H" in Volume 1).

The federal government should re-instate and expand a comprehensive monitoring and surveillance program for mercury and other important contaminants (e.g., PCBs) with a statistically appropriate sampling strategy covering all of the commonly consumed fish sold in the United States, including documentation of the origin and sizes of the fish analyzed. The results of federal monitoring and surveillance programs for commercial fish should be provided to the public and to regulatory agencies in a comprehensive and timely fashion.

Research is needed to identify factors contributing to mercury concentrations in various species of fish representing diverse geographic regions and ecosystems, and linking such levels to the various known sources of natural and anthropogenic mercury.

A comprehensive database on taxonomic, spatial, and temporal trends in mercury (and other pollutant) concentrations in fish, should be established to provide an indicator of the success of current and future control measures and to identify new or expanding sources of mercury.

Studies of pollutant concentrations in fish should include mercury as well as organochlorines, as a substantial portion of the expense lies in the sampling, collecting, and specimen preparation.

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, NJ should:

- **Identify demographic characteristics and exposure patterns of population groups in NJ that consume large quantities of fish. (From Recommendation "M.4." in Volume 1).**

Systematic data collection on the patterns and trends in fish consumption should be established on a national level to provide important data on the species consumed, amount consumed, types of food preparation, as well as identifying the most highly exposed subgroups. Data should be collected and reported in a form that can be desegregated on a state-by-state basis. This survey should oversample high end consumers and should be repeated at least every 10 years to capture trends due to new information and changing demography.

Chapter 5 - HUMAN HEALTH EFFECTS AND TOXICOLOGY

A. Introduction

All mercurial compounds are toxic and they affect many organ systems both during pre-natal and post-natal development and in adulthood. Mercury compounds are neurotoxic. Some are immunologically active. The main toxicity stems from the binding of mercury to sulfhydryl groups of enzymes and other proteins, thereby disrupting their structure and function. This interferes with basic cellular processes and damages or kills cells. The different forms of mercury differ in their ability to penetrate membranes and gain access to organs such as the brain. It is generally the neurotoxicity, that is of greatest importance, although some forms of mercury damage the kidneys and some compounds are highly corrosive to skin and mucous membranes.

Overall, the toxicity to the developing nervous system of the fetus is considered the most critical endpoint. However, recent evidence suggests that cardiovascular effects can occur in adults at comparably low doses. It will be necessary to follow the emergence of additional studies in the future. The toxicology of mercury compounds has been reviewed by ATSDR (1999a).

B. Methylmercury Neurodevelopmental Toxicity

The following is presented as a brief introduction to and summary of the current understanding of the toxicology of methylmercury (MeHg). Significant uncertainties remain, and a full presentation of the available data and their accompanying uncertainties is beyond the scope of this report. More complete discussion and analysis can be found in several recent publications:

- The National Research Council's *Toxicological Effects of Methylmercury*, (NRC 2000);
- The US EPA's *Mercury Report to Congress* (USEPA 1997c and 1997e);
- The ATSDR 1999 update of its *Toxicological Profile for Mercury* (ATSDR 1999a) and
- The report of the National Institute of Environmental Health Sciences' Workshop on *Scientific Issues Relevant to Assessment of Health Effects from Exposure to Methylmercury (NIEHS 1998)*

Entire issues of journals have been devoted to methylmercury toxicity (see, for example, the winter 1995 issue of Neurotoxicology, Cramer 1995), although the toxicity of methylmercury has long been known.

1. Minamata Disease

Although it has long been known that high level methylmercury exposure resulted in profound impacts on central nervous system function in humans, more recent investigations of animals (Newland and Paletz 2000a; Newland and Rasmussen 2000) and populations with lower level exposure (Rice 2000), have identified specific functional effects, for example, sensory effects and subtle changes in response to conditioning paradigms, rather than memory. Performance decrements were found at doses of 10μg/kg/day, while visual-evoked potential changes and ataxia occurred at doses two orders of magnitude higher (Newland and Paletz 2000).

Because of epidemics of widespread poisoning in Minamata in the 1950's and later in Nigata, Japan, MeHg was one of the first environmental contaminants to be recognized with the potential to adversely affect large numbers of people with relatively low levels of exposure. For many years, fisher families had suffered a strange debilitating disease, which was finally recognized as methylmercury poisoning (Kurland et al. 1960). These epidemics were followed by a mass poisoning in Iraq in 1971-1972 when people became sick after ingesting grain that had been treated with mercurial pesticide. In each of these cases, a range of neurological effects, reflecting damage to the central nervous system, was seen in the exposed populations of adults and older children. The severity of the effects were closely linked to the total dose, and ranged from paresthesias (pins and needles), to impairment of speech and gait, deafness, blindness, coma and even death.

In both the Japanese epidemics (where exposure was from mercury-contaminated fish) and the Iraq epidemic (where exposure was from grain treated with a mercurial fungicide), infants born to mothers with high mercury levels suffered qualitatively different effects than their mothers. These involved the central nervous system and included mental retardation, cerebral palsy, and severe delays in the attainment of developmental milestones (e.g., sitting, standing, walking, and talking). This syndrome became known as Congenital Minamata Disease. Data suitable for developing an understanding of dose-response were gathered from a subset of the Iraq cohort. Maternal exposure during pregnancy was estimated by analyzing mercury levels in segments of maternal hair that grew during the MeHg poisoning period. Data on adverse effects was collected from clinical neurological examinations and from maternal recall of developmental milestones.

Based on an analysis of the Iraqi data, the USEPA calculated a benchmark hair concentration for MeHg (lower 95% confidence interval on the concentration corresponding to a 10% response rate) of 11 ppm (US EPA 1995b). This hair concentration was converted to an estimate of average daily intake of 1.1 µg /kg/day by use of a pharmacokinetic model. An overall uncertainty factor adjustment of 10, addressing inter-individual variability and lack of complete data on other possible adverse effects, was applied to this dose to yield the current Reference Dose (RfD) for MeHg of 0.1 µg /kg/day.

Significant uncertainties in the design and interpretation of the Iraqi data have been identified. Comparison of the occurrence of developmental delays in the Iraqi population to those in populations with comparable mercury exposures resulting from fish consumption rather than from the consumption of treated grain (over a relatively shorter period of time), did not confirm the developmental delays predicted from the dose-response analysis of the Iraqi data (NRC, 2000).

The adverse neurological developmental effects recorded in the Iraqi study were all classifiable as clinical effects. That is, they are conditions that can be recognized as abnormal by the individual or detected by a clinician evaluating that individual. In contrast, sub-clinical effects are those that would result in a decrement in function but would not be recognized as abnormal by the individual, nor would they be detectable without specialized tests. It is a typical feature of dose-response curves that subclinical effects occur at exposures below those that result in clinical effects. Unlike other adverse outcomes, such as cancer for instance, in which a tumor either is or is not present, neurological function operates on a continuous scale. An example of this is IQ performance. An individual, whose IQ performance is within the range of normal, could still have a lower IQ score than he or she would have had in the absence of exposure to MeHg.

It is possible to compare the IQ scores of groups of children with high in-utero exposure to mercury to children with low in-utero exposure. If MeHg exposure resulted in sub-clinical reduction of IQ performance, such effects might be expected to be manifested as differences in mean IQ scores between such groups of children. Such considerations underlie the current guidance for identifying and controlling low-level lead exposures in children (ATSDR 1999b).

The studies discussed below, which followed the Iraqi study, investigated populations that are exposed to MeHg through fish consumption. As such, they are more appropriate for consideration of exposures in the US (and NJ). These populations were not overtly poisoned and no cases of Congenital Minamata Disease occurred. They are discussed in more detail because they provide the rationale for attempts to reduce mercury contamination and exposure. For comparison, hair concentrations of mercury in the US are typically less than 1 ppm.

Adverse effects that may occur in the study populations described below are determined on the basis of epidemiological studies examining the possible association between MeHg exposure during gestation and decreased performance on specific developmental neurological and neurobehavioral tests. Such associations are investigated after controlling for other potential determinants of performance. These include birth weight, breastfeeding, income, ethnicity, maternal education, maternal smoking, alcohol consumption, general health status, nutritional status, etc. The determination of an association is, therefore, based on a statistical analysis, which attempts to isolate the specific influence of MeHg from among other possible determinants of test outcome.

2. *New Zealand Study*

Subsequent to the Iraqi poisoning, a study was undertaken in New Zealand focusing on children of mothers who consumed fish (mostly shark) (Kjellstrøm et al. 1986; 1989). There were no known cases of clinical effects attributed to MeHg exposure in this population. Approximately 90% of the mothers had hair mercury levels of 6-12 ppm during pregnancy. Maternal hair mercury levels >10 ppm and possibly those in the range of 6-10 ppm were found to result in decrements in tests of cognitive ability (IQ), verbal ability and motor function when other influences (e.g., ethnicity) were taken into account. A recent re-analysis of these data (Crump et al. 1998) suggested benchmark concentrations in the same range as those derived by the USEPA from the Iraqi data.

3. *Seychelles Study*

An ongoing study in the Seychelles Islands (in the Indian Ocean, off the eastern coast of Africa) has been following a cohort of about 700 children (main cohort) whose mothers were exposed to MeHg from fish consumption during pregnancy. The Seychelles Islands were chosen for study because fish is a staple of the diet in that population. The median maternal hair mercury concentration is about 6 ppm with about 20% >12 ppm. The children were evaluated at 6, 19, 29, and 66 months of age. Separate pilot studies of 789 children of mixed ages (from <10 weeks to >2 years old), and a group of 247 children at 66-months old were also conducted (Davidson et al. 1998). In the main cohort, a significant relationship was observed between maternal MeHg exposure and decreased activity level in boys. For all other tests, including intelligence, psychomotor function, visual attention, visual recognition, gross neurological function, and general developmental competency (Denver Developmental Screening Test), no association between maternal exposure and test outcome was observed. In the mixed age pilot study, maternal hair mercury above 12 ppm was associated with an increase in combined abnormal and questionable performance. In the 66-month pilot study, maternal hair mercury was clearly associated only with decreased auditory comprehension, but not eight other tests of intelligence, language, and motor skills. Given the large number of separate tests administered in this study overall, it is not clear if the few observations of associations reflect true associations, or if they occurred by chance alone. In general, however, the Seychelles study has not found a strong relationship between maternal MeHg exposure and impaired neurologic performance in children. The authors generally consider this a "negative study".

4. Faroe Island Study

Another major ongoing prospective study of children is being conducted on the Faroe Islands (located in the North Atlantic between Scotland and Iceland, and politically part of Denmark) (Weihe et al. 1996). Here, too, people eat large quantities of fish, frequently supplemented by the meat of Pilot Whale. A cohort of about 900 mothers and children is being followed and the children have been tested at 7 years old. Exposure was measured both as maternal hair mercury concentration, and as fetal cord blood mercury concentration (obtained at delivery). The median maternal hair mercury concentration was 4.3 ppm with 15% >10 ppm (Grandjean et al. 1997).

Pilot Whale has high concentrations of PCBs, as well as MeHg. Since PCBs are also known to adversely affect neurological development, the interpretation of the results from this study is somewhat complicated. In whales, MeHg tends to be found mostly in muscle tissue, while PCBs tend to be found in blubber. Some Faroese eat whale blubber and others do not. To some extent, this permits statistical separation of MeHg and PCB exposure and effects on a population basis.

In eight of 20 neuropsychological tests (including language, attention, and memory), decreased test performance was associated with cord blood mercury concentration (similar and only slightly weaker associations were also observed with maternal hair mercury concentration). In four of these eight tests, PCBs were also associated with decreased test performance. However, statistical analysis allowed the researchers to determine that even if PCBs are contributing to the impairment, there was an independent effect of MeHg on performance. The types of functions affected by MeHg appear to be generally comparable to those found in the New Zealand study (see above).

The National Institute of Environmental Health Sciences (NIEHS) held a workshop in 1998 to assess the current studies relating to the human health impact of MeHg. The NIEHS workshop (NIEHS 1998) concluded that "Results from the Faroes and Seychelles studies are credible and provide valuable insights into the potential health effects of methylmercury."

The recent NRC (2000) report noted the similarities in both types of adverse responses and in the quantitative dose-response relationship between the Faroes and New Zealand studies. That report investigated several possible reasons for the differences observed between these two positive studies and the negative Seychelles study. These include:

- different types of exposure measurements (hair vs. blood);
- different types of tests;
- different ages at testing;
- the potential influence of PCBs and other exposures;
- different fish consumption patterns;
- random statistical chance; and
- dietary and nutritional factors.

However, with the possible exception of statistical power, none of these possibilities appears to provide a sufficient explanation for these differences. The NRC committee concluded that the two positive studies provided a credible basis for the derivation of a Reference Dose (RfD), and identified the Boston Naming Test (a measure of verbal intelligence) in the Faroes study as the most appropriate basis for a RfD.

The NRC Committee conducted dose-response modeling, and concluded that in-utero exposure to MeHg resulting in a cord blood mercury level of 58 µg/l (corresponding to a maternal hair level of about 12 ppm) would be associated with a doubling of the percent of children performing at the lowest 5% level on this test. The NRC also examined the potential confounding and/or interaction of PCB exposure with MeHg exposure in the Faroes study. The dose-response relationship between MeHg and performance was no different among subgroups with low and high PCB exposure. Thus, whether or not PCB influenced performance, there was an independent effect of MeHg.

The report recommended that this blood concentration, converted to mean maternal MeHg dose (µg/kg/day), be divided by an uncertainty factor adjustment of 2-3 to account for population variability in the conversion to an intake dose. An additional uncertainty factor to account for other health effects such as cardiovascular, immunotoxic, and delayed neurological effects, which may be occurring at lower levels of exposure, was also recommended. The report concluded that an overall uncertainty factor adjustment of "at least 10" was appropriate. This gives a maternal hair concentration which is essentially equivalent to that underlying the existing US EPA RfD (11 ppm), and applying an equivalent uncertainty factor adjustment (10) based, albeit, on somewhat different rationale, would result in an RfD that is quantitatively unchanged from that derived from the Iraqi poisoning (0.1 µg/kg/day).

Based on review of the NRC report (NRC 2000) as well as the NIEHS report, and on additional independent review, the US EPA has recently re-affirmed its former RfD of 0.1 µg/kg/day, albeit supported by new data and a new rationale. In 1999, the ATSDR derived a Minimal Risk Level (MRL) value - essentially equivalent to an RfD - for MeHg of 0.3 µg/kg/day based primarily on the absence of observed effect in the Seychelles study, and only indirectly addressing the positive findings from the Faroe Islands. These values are not very far apart and given the remaining uncertainties, it is likely that the lower value will be protective of most children.

5. Other Studies

The neurologic and neurobehavioral effects of mercury on children and adults have been studied in other areas, although seldom with a complete prospective design.

In their pilot study of Peruvian neonates born to mothers with a range of MeHg values up to 30 ppm in hair, Marsh et al. (1995) performed neurologic examinations and inquired about developmental landmarks in a sample of 110 mother-infant pairs. They provide only P values on correlations, rather than actual mercury or correlation levels. Although they consider their study negative, there are suggestive positive correlations (p values of 0.10-0.13), particularly in females, suggesting delayed development.

Neurobehavioral effects have been more clearly demonstrated in Amazonian Indians with high fish consumption and elevated mercury (Lebel et al. 1998). These results were considered influential by the National Research Council (NRC 2000) in conjunction with the Faroe Island results.

6. *Summary and Conclusions: Methylmercury Neurodevelopmental Toxicity*

It is clear that MeHg is a neurotoxin, which can cause a range of developmental abnormalities in children exposed *in-utero*. The critical question for assessing the impact of mercury on human health is whether, within the range of exposure associated with consumption of sport and commercial fish, there is a significant risk of adverse effects. Although historical and ongoing studies have not produced a clear-cut and unambiguous answer to this question, there are credible scientific data, which suggest that at some currently encountered levels of fish consumption, significant risks can occur. These risks relate to subtle and population-based deficits in developmental performance, mostly within the range of "normal" performance. It appears that the current US EPA RfD for protection against such adverse effects, 0.1 μg/kg/day, is appropriate and protective. Additional data from ongoing studies may further clarify this picture, but it is likely that uncertainties will remain for the foreseeable future.

C. Methylmercury Adult Toxicity

The adult toxicity of MeHg has been characterized largely through studies of the poisoning episodes in Japan, and Iraq (ATSDR 1999a; US EPA 1997e; WHO 1990). These studies revealed a continuum of effects on the central nervous system, including death, but extending through (in order of decreasing threshold of effect) ataxia (lack of motor coordination), dysarthria (difficulty in speech), deafness, and paraesthesia (numbness or tingling characteristically in the lips and extremities). The onset of these effects, even at high doses, characteristically has a long latency period of weeks to months. Dose-response modeling for paraesthesia as the most sensitive (critical) toxic effect from the several populations, and studies yielded good agreement in terms of the threshold for occurrence. A LOAEL (lowest-observed-adverse-effect-level) dose estimate of 3.0 μg/kg/day was identified. This dose approximately corresponds to a hair mercury concentration of 50 ppm. The US EPA applied an uncertainty adjustment of 10 to the LOAEL to estimate the NOAEL (no-observed-adverse-effect-level) to derive a RfD (Reference Dose) of 0.3 μg /kg/day. No uncertainty adjustment was used to address other common uncertainties (e.g., sensitive sub-populations).

This RfD was officially adopted by the US EPA in 1985. It was officially superseded by the current US EPA RfD of 0.1 μg/kg/day, which specifically addresses in utero developmental effects. Because the current (developmental) RfD is lower than the previous RfD, it is considered to be protective of all segments of the population. The US EPA has not, however, revised the assumptions or conclusions underlying the former RfD to provide guidance for protection of adults from health effects of MeHg. As such, it might be applied to consideration of safe exposure to MeHg by male adults, and adolescents, and women who are not pregnant or planning pregnancy within a year. This value (0.3 μg/kg/day) forms the basis for the current NJ Department of Environmental Protection's advisories for fish consumption for MeHg for the "general" population (Toxics in Biota Committee 1994).

Since the adoption of the former (i.e., "adult") MeHg RfD by the US EPA in 1985, additional information on the non-developmental toxicity of MeHg has become available. Some of this information suggests that the basis for the "adult" RfD may not address more subtle neurological effects of MeHg, and/or may not be protective against non-neurological effects of MeHg. Kosatsky and Foran (1996) have pointed out several weaknesses in studies of potential MeHg effects in adults with hair concentrations below 50 ppm. They suggest that these weaknesses call into question the ability of those studies to identify possible effects at levels below those identified as the basis of the "adult" RfD. Among these weaknesses is the concentration on more obvious and clinical manifestations of MeHg toxicity (e.g., paraesthesia) to the general exclusion of more subtle (e.g., performance-based) endpoints. For example, long-term follow-up of the population exposed to MeHg in Minamata, Japan (Harada 1995; Kinjo et al. 1993) indicates worsening of MeHg effects (including more subtle subjective complaints) with aging.

There also appears to be uncovering of latent effects with aging among those previously asymptomatic. The worsening and/or uncovering of effects with aging was not addressed in the dose-response assessment for the "adult" RfD. Studies in the Brazilian Amazon of populations consuming MeHg contaminated fish (without direct exposure to mercury use in gold mining) suggest neurotoxic effects including: deficits in visual contrast and color discrimination; visual field constriction; and disorganized movement with increasing MeHg exposure in adults with hair mercury concentrations below 50 ppm (Lebel et al. 1998; Lebel et al. 1996). As these individuals may have been exposed starting in utero however, these observations may also reflect developmental effects of MeHg. In eastern Finland adult men have both elevated fish consumption and high mortality from coronary heart disease. Controlling for other risk factors, Salonen et al. (1995) found that the risk of coronary heart disease, cardiovascular disease, and acute myocardial infarction increased with mercury exposure from fish consumption. The risk of an acute myocardial infarction doubled, and the risk of death from cardiovascular disease increased 2.9 fold for a hair mercury level of 2.0 ppm compared to background levels. This is a lower level of exposure than that associated with adverse neurological developmental effects (see previous section). Although further confirmation of such associations is needed, such findings suggest that the current "adult" RfD for MeHg may not be adequate for protection against more subtle neurologic effects than those originally considered, and/or may not address the most critical endpoints of "adult" MeHg toxicity.

The recent NRC (2000) report recommended that while an RfD for methylmercury should be based on neurological developmental effects, uncertainty factor adjustments should be applied that address the potential occurrence of non-developmental effects such as cardiovascular and immunotoxicological effects at doses lower than those protective against neurological developmental effects. The implication of such an RfD is that it would be protective against both developmental and non-developmental (i.e., adult effects of methylmercury). The US EPA adopted an RfD in July 2001 that addresses "adult" effects. Such an RfD logically precludes the application of the former "adult RfD".

The former US EPA RfD for MeHg (0.3 μg/kg/day) was based on clinical neurological effects observed in adults. While this value has been superceded by the current RfD for developmental effects, it continues to be used to address the non-childbearing portion of the population. Current evidence suggests that more subtle neurological effects and/or non-neurological effects of MeHg may not be addressed by this "adult" RfD. Research, specifically addressing the potential for adverse effects at lower levels of exposure than those addressed by the "adult" RfD, should be undertaken.

D. Toxicology of Inorganic Mercury

1. Introduction

The toxicology of inorganic mercury can be divided into separate categories of mercury salts (essentially Hg^{++}) and elemental mercury vapors (Hg^0). At exposure levels likely to be encountered in the environment, the target organs and critical health endpoints for each form are somewhat different, and can be considered separately. This report presents only a brief summary of the toxicology of these species of inorganic mercury. Although the mercury in the atmosphere is predominantly the inorganic form, it occurs at concentrations generally far below those of health concern. Thus, most aspects of inorganic mercury toxicity were beyond the scope of the Task Force. Further information and a guide to more detailed sources can be found in the ATSDR Toxicological Profile for Mercury (ATSDR 1999a), and kidney toxicity has been reviewed by Zallups (1997).

2. *Ionic Mercury and Mercury Salts (Hg^{++})*

Absorption of the salts of Hg^{++} by ingestion varies by their solubility. Inorganic mercury absorption ($HgCl_2$) increases at alkaline pH, and the mercury compounds are transported bound to high molecular weight proteins (Endo et al. 1986). In adults, about 15% of an oral dose of mercuric chloride ($HgCl_2$) are absorbed. However, young animals absorb a larger fraction of the ingested dose, and this is presumably true of children as well. The most common form of Hg^{++} in the environment is mercuric sulfide (HgS) which has low solubility and is very poorly absorbed. In the body the highest concentrations of Hg^{++} are found in the liver and kidney. Hg^{++} does not readily cross either the blood-brain barrier or the placenta. The kidney appears to be the most sensitive organ to Hg^{++} exposure. Although degeneration and atrophy of the renal tubular epithelium resulting in kidney dysfunction are characteristic, mercury also damages the renal glomerulus through an autoimmune reaction resulting in albuminuria. This effect is the basis for the current US EPA reference dose (RfD) for Hg^{++} of 0.3 μg/kg/day, based on $HgCl_2$. The extent to which this value is applicable to health effects in humans is not clear since it was derived from exposure of a strain of rat known to be sensitive to auto-immune glomerular effects. Its applicability appears to be based on the assumption that this test system is likely to predict effects in sensitive humans.

3. *Elemental Mercury (Hg^0)*

Hg^0 is very poorly absorbed by ingestion or dermal contact. However, Hg^0 is a liquid at room temperature with a relatively high vapor pressure which yields mercury vapor which is readily absorbed in the lung and results in its significant potential for toxicity. Elemental mercury that is inhaled is either exhaled, retained in the upper or lower respiratory tract, or absorbed into the circulation. A variety of studies reviewed by Leggett et al. (2001) indicate that only about 20% of inhaled mercury is exhaled. They estimate a three-order absorption with about 56% of the inhaled mercury absorbed into the blood very rapidly and 87% absorbed within hours and the remainder within days. Hg^0 absorbed into the blood from the lungs can cross both the placental and blood-brain barriers. In most organs, Hg^0 is metabolized relatively rapidly to Hg^{++}. Long-term inhalation exposure can lead to Hg^{++} accumulation in the kidneys. The brain, however, is the critical organ for Hg^0 toxicity. Hg^{++} is also formed from Hg^0 in the brain. It is not clear whether it is the initially deposited Hg^0, or its metabolite, Hg^{++}, which is the ultimate source of toxicity.

Acute inhalation of high levels of Hg^0 vapor (e.g., due to heating of metallic Hg) can result in death from asphyxiation, lung edema, and necrosis of lung tissue. Long-term exposure to lower levels can result in frank neurological effects such as tremor, personality changes, depression, difficulty sleeping, memory loss, etc. This suite of effects has long been known as erethism, characterized by emotional lability with alternating shyness and combativeness. The critical effects with chronic exposure to much lower levels of Hg^0 vapor are fine tremors and slight reductions in coordination. A recent study of dentists exposed over long periods to Hg^0 in the preparation and installation of amalgam fillings reported subtle changes in tests of neurological performance. The current US EPA Reference Concentration (RfC) for Hg^0 of 0.3 $\mu g/m^3$ is based on fine tremors and memory disturbances observed in studies of occupational exposure. Currently the potential for exposure to Hg^0 in the NJ population is from cultural/folk uses of mercury, from dental amalgams, and from indoor spills of Hg^0

resulting from breakage of thermometers or mercury-containing instruments (e.g., barometers).

4. Summary and Conclusions: Toxicology of Inorganic Mercury

Salts of inorganic mercury primarily affect the kidney, but are not well absorbed. Elemental mercury primarily affects the central nervous system, and is well absorbed by inhalation, but not by ingestion. Subtle neurological effects may occur with even low levels of exposure, making elemental mercury in residences resulting from spills and intentional use potentially dangerous.

E. Recommendations

Reduce exposures from cultural uses of mercury. To accomplish this, NJ should:

1. **Complete research and evaluate available data on cultural uses and associated exposures.**
2. **Provide outreach and education materials to communities and health professionals.**
3. **Develop and implement appropriate legislation and regulations that limit the sale of elemental mercury, except for medical and other approved uses, reflecting the NEWMOA model legislation.**

(From Recommendation "J.1, J.2 and J.3" in Volume 1)

The federal government and, to the extent possible, the State of NJ should pursue research to elucidate the extent of exposure of the population to elemental mercury from dental amalgams and from cultural/folk uses. Research should also address the potential for combined developmental and/or adult toxicity from joint exposures to methylmercury and elemental mercury.

The federal government should pursue the human health-based objectives of the US EPA's Mercury Research Strategy to clarify the significant remaining uncertainties in the neurodevelopmental toxicology of methylmercury.

Chapter 6 - ECOLOGICAL EFFECTS OF MERCURY

A. Introduction

There is a huge and rapidly growing scientific literature on the distribution of mercury in ecosystems. Mercury has been measured in aquatic and terrestrial invertebrates, in a variety of plants, and in many higher organisms including humans. High concentrations of mercury have been associated with developmental and behavioral abnormalities, impaired reproduction and survival, and in some cases with direct mortality. There is evidence that mercury may act synergistically with organic pollutants such as PCBs (Gochfeld 1975). The Task Force was charged to address the question: "Does the current body of scientific knowledge indicate that mercury in the environment is at levels of potential wildlife and ecological impact?"

Mercury is among the most extensively studied of all the environmental pollutants, but the information on the distribution in various environmental or body compartments exceeds information on effects at the organism, population and ecosystem level. There remain substantial gaps in our understanding of the effects of mercury on different kinds of organisms, on different trophic levels, and on ecosystem function itself. Ecological effects can be measured by some impacts, presumably adverse, on microorganisms, plants, and animals that make up the decomposer, producer and consumer trophic levels of ecosystems. The endpoints in individuals exposed to mercury can include changes in behavior, physiology, reproduction, or longevity, as well as acute effects such as morbidity and mortality. Endpoints among species can include changes in survivorship and population structure, population declines or local extinction. Ecological endpoints include changes among the species interactions, usually reflected in food webs, as well as changes in the cycling of matter or the patterns of energy use and production.

As mercury is transferred from one trophic level to another, there can be direct contamination (uptake from the water column through gills or by ingestion) as well as uptake from food. These can be separated by raising organisms in both contaminated and "clean" water and providing them with food that has low and high levels of mercury. Simon and Boudou (2001a,b) have shown that crayfish and carp take up both Hg^{++} and MeHg by both routes. Carp have concentration factors (compared to water) from 1000 for Hg^{++} to 13,000 for MeHg. The trophic transfer rate for carp was estimated at 2% for Hg^{++} and 13% for MeHg (Simon and Boudou 2001a) and for crayfish at close to zero for Hg^{++}, but 20% for MeHg (Simon and Boudou 2001b).

Eisler (1987) summarized the ecotoxicology of mercury. Mercury and mercury compounds have no known beneficial biological function. Forms of mercury with relatively low toxicity can be transformed into forms with very high toxicity. Methylmercury can be accumulated through food chains resulting in higher exposure to upper trophic levels. Mercury is a mutagen and teratogen and the uses and releases of mercury should be reduced, "because the difference between tolerable background levels of mercury and harmful effects in the environment is exceptionally small." (Eisler 1987)

Although U.S. EPA (1997d,e) stated that the ecosystem effects of mercury are incompletely understood, and that no studies were found of the effects on intact ecosystems, they did identify the characteristics of ecosystems potentially at risk from mercury releases to air. These included systems located in areas that experience high levels of atmospheric deposition, those with surface waters already impacted by acid deposition, those possessing characteristics other than low pH that result in high levels of mercury bioaccumulation in aquatic biota, and those with species which have been subject to point source discharges of mercury (e.g., industrial outfalls).

Many studies have shown that mercury becomes widespread in both abiotic and biotic components of ecosystems (Pillay et al. 1972; Peakall and Lovett, 1972). Much of the effort involving mercury investigations has focused on aquatic rather than terrestrial ecosystems due to the methylation and bioaccumulation of the highly toxic MeHg in these systems. In addition, most studies have examined the effects of mercury on individuals or species and have not examined ecosystem effects (e.g., biodiversity, food web structure, energy flows).

B. Biomagnification

Biomagnification (sometimes called bioamplification) of mercury through a food chain is a primary cause for much of the concern with this metal. This term defines the process where at each level in a food chain, from bacteria to plankton to tiny crustacea, small fish, larger fish, and fish-eaters, organisms take in more mercury than they excrete thereby accumulating the excess in their organs. Thus the ultimate concentration in any organism is higher than the mercury concentration in its food. This results in elevated concentrations of mercury in higher trophic (feeding) levels of the food chain. These concentrations can be harmful to the organism itself, or to predators of those organisms. Figure 2.1 illustrates a hypothetical pattern of biomagnification, through which an infinitesimally low concentration of mercury (parts per trillion in water) can reach biologically dangerous concentrations (parts per million) in larger predators including humans. These theoretical values are reflected in Table 2.5. It should be noted that each step shown is for illustration purposes only and is not necessarily reflective of actual values measured in the environment.

Table 2.5. Biomagnification of Methylmercury in a Hypothetical Aquatic Food Chain.

Trophic Level	Concentration
Water	1 ng/L = 1 ppt
Bacteria and phytoplankton	10 ng/kg of water = 10 ppt
Protozoan/zooplankton	100 ng/kg = 100 ppt
Insect larvae	1 µg/kg = 1 ppb
Fish fry	10 µg/kg = 10 ppb
Minnows	100 µg/kg = 100 ppb
Medium-sized fish	1 mg/kg = 1 ppm
Large predators (fish, birds, humans)	10 mg/kg = 10 ppm = 10µg/g

Mercury bioaccumulation was demonstrated in a terrestrial forest ecosystem in Slovenia. Total mercury levels in soil exceeded 2000 ppm close to the Iridja smelter, and ranged from 14 to 886 ppm further afield of which less than 1% (0.01 to 0.6%) was MeHg. Plant samples ranged from 50 ppm down to less than 1 ppm (mostly non-accumulator species), of which up to 2% were MeHg. Air mercury was mostly in the 1-100 ng/m^3 range, with up to 1 ug/m^3 close to the smelter and 1.8 ng/m^3 at a distant reference site. Generally, sites closer to the smelter had much higher total and lower percent of MeHg than sites further away. Large herbivores (Roe Deer and Chamois) had mercury levels in the 20 to 20,000 ppb ranges (kidney>liver>muscle), with a maximum kidney concentration of 56 ppm. Methlymercury comprised less than 1% of total mercury in kidney, 4-10% in liver, and 35-48% in muscle (Ganmus et al. 2000). They had only three carnivore samples (two Lynx and one Wolf) that did not show much higher levels than in the herbivores, but the MeHg comprised about 10-20% of kidney, 17-33% of liver and 50-83% of the muscle MeHg (Gnamus et al. 2000), which suggests a preferential retention of MeHg from the prey. Thus, whereas the concentration factor(lynx-deer) was less than one for total mercury it exceeded one for MeHg, and was proportionally higher in control animals with lower total mercury, suggesting a ceiling effect of high mercury on the concentration factor.

A discussion of the tissue concentrations and effects of mercury on various invertebrate and vertebrate groups is provided below as an example of the ecological impacts of mercury. Toxicity testing results have generally indicated that early developmental stages of organisms were the most sensitive, and organomercury compounds, especially methylmercury, were more toxic than inorganic forms (Eisler 1987).

C. Toxicity of Mercury to Algae and Micro- and Macroinvertebrate

Sjoblom et al. (2000) found that direct uptake from water by fly larvae (*Chaoborus* sp.) was ten times higher for MeHg than for Hg^{++}. Organic matter in the form of humic aids decreased the uptake of both MeHg and Hg^{++} substantially (Sjoblom et al 2000). Similarly, Lawrence and Mason (2001) found that amphipods living in organic-rich sediment accumulated less mercury than those living in organic-poor sediments.

Planktonic unicellular algae, such as *Chorella vulgaris*, have a high capacity to bioaccumulate organic mercury, as do fresh water macrophytes such as *Elodea densa*. Experimental exposure of this plant to a 1 ppb concentration of methylmercury chloride for 10 days produced an average concentration in the leaves of 15 ppm, a 15,000-fold bioconcentration factor. Primary consumers, such as the crustacean *Daphnia*, readily accumulate mercury by eating contaminated algae. They too accumulate a higher concentration of MeHg than their algal food. Thus begins the biomagnification of mercury in the food chain when the *Daphnia* are consumed by other organisms such as insect larvae or small fish.

Toxicity tests with the rotifer, *Brachionus calyciflorus*, designed to incorporate natural stressors such as food shortage, Cyanobacteria blooms, and predation have been conducted to determine if ecological relationships affect the impact of anthropogenic toxicants on rotifer populations. Results indicated that natural stressors (i.e., food limitation and Cyanobacteria) exacerbate the stress due to contaminants, such as mercury (Ceccine 1997).

Planarians (*Dugesia dorotecephala*) are aquatic flatworms used as a test species for mercury toxicity because of their sensitivity to this metal. These animals (about 1 cm long) ordinarily have remarkable powers of regeneration and are able, for example, to grow a new head after decapitation. However, grossly visible abnormalities in head regeneration occurred when decapitated planarians were exposed to 0.1 ppm methylmercury. A much more sensitive indicator of toxic effects is the suppression of fissioning, a natural process of division in these animals. Concentrations as low as 0.03 ppb, a concentration approximating the lower mercury levels found in "unpolluted" US streams and ocean water, were sufficient to inhibit fissioning (Best et al 1981).

Mercury exposures of approximately 0.1 ppm in water have been shown to severely affect heart rate rhythms in the freshwater crab, *Potamon potamios* and in the crayfish, *Astacus astacus*, interfering with the normal circadian rhythm patterns in these animals. Such effects on the heart are then followed by substantial mortality in these animals under experimental conditions (Styrishave & Depledge 1996). Exposure of fiddler crabs to 0.5 mg/L of mercury resulted in the inhibition of limb regeneration and ecdysis (molting) (Callahan & Weis, 1983). These levels are far above background levels in surface water. Even in highly contaminated Berry's Creek, mercury levels range from 0.74 to 17.6 µg/L (total mercury) (Exponent 1998). These values appear to be well below the 100-500 µg/L effect levels in the crustacean studies.

D. Toxicity of Mercury to Terrestrial Invertebrates

Earthworms, as an example of terrestrial invertebrates, exhibited complete mortality at methylmercury concentrations of 25 mg/kg (ppm) in soil in a 12-week exposure (Beyer et al. 1985). Inorganic mercury concentrations of 0.79 mg/kg in soil were toxic to 50% of the earthworms in a 60-day study, and 100% mortality was observed at 5 mg/kg (Abbasi and Soni 1983). However, it is not possible to determine the relative toxicity of these two forms of mercury based on these two earthworm studies, which used different systems and two different families of earthworms (Efroymson et al. 1997).

E. Toxicity of Mercury to Fish

There is a very large but non-systematic literature on mercury levels in fish, particularly with regard to tissue concentrations, which bear on whether they are safe to eat. Thus fish have been studied more as a vector of human exposure than as an ecological target of mercury. Young fish hatch with a burden of mercury acquired from the egg, but, as they grow in size, the diet-derived mercury and mercury taken up directly from water exceed the egg contribution. Comparing Walleye larvae from a contaminated lake with those from uncontaminated lakes indicates that the MeHg concentration of young fish involves both maternal contributions via the egg as well as ingestion of MeHg from water and food (Latif et al. 2001).

In many studies of mercury in fish there is an increasing concentration with the size and age of the fish (e.g., Latif et al. 2001, Redmayne et al. 2001). Where this is not found, it may be due in part to inadequate sample size, or inadequate range in mercury concentrations or fish size (Huckabee et al. 1979). Hatching success of Walleye eggs declined significantly with increasing waterborne MeHg, even in the range of 0.1-7.8 ng/L. Likewise embryonic heart rate declined, but larval growth was not affected (Latif et al. 2001).

Largemouth Bass upriver from a presumed contamination source in the Savannah River averaged 0.30 ppm total mercury in muscle, compared with an average of 0.68 ppm below it. Higher trophic level fish, bass and Bowfin, had higher levels of mercury than lower level fish such as sunfish (averages less than 0.25 ppm) (Burger et al. 2001b).

Toxicity values for freshwater and marine fish are given in Table 2.6. A wide range of acute toxicity values is evident with methylmercury being more toxic than inorganic mercury. Chronic toxicity values are much lower than acute values and highlight the adverse effects of relatively low concentrations of mercury and methylmercury in water (i.e., < 1 µg/L). Additional examples of the toxicity of mercury to fish can be found in Chapter 8, Section D.

Table 2.6. Toxicity Values for Aquatic Species (EPA 1997d and 1997e).

Organism	Hg++ (µg/L) (as HgCl or $HgNO_3$)	Methylmercury (µg/L)
ACUTE (LC50) (1)		
Freshwater invertebrates	2.2 (cladoceran)1 to 2,000 (insect larvae)	Not available
Freshwater fish	30 (guppy) to 1,000 (Tilapia)	Not available
Rainbow Trout	155 to 420	24 to 84
Saltwater invertebrates	3.5 (mysid shrimp)1 to 400 (soft clam)	Not available
Saltwater fish	36 (juvenile Spot) to 1,678 (flounder)	51.1 (Mummichog)
CHRONIC (EC50) (1)		
Fresh-water invertebrates (cladocerans or water fleas)	0.96 to 1,287	<0.04
Fresh-water fish	<0.23 (minnow) to <0.26 (minnow)	0.29 (Brook Trout) to 0.93 (Brook Trout)
Saltwater invertebrates	1.131 (mysid) (2)	Not available

(1) LC5O concentration that results in death in 50% of the organisms and EC50 = concentration at which 50% of the exposed animals show a particular effect.
(2) Common name for cladocerans is water flea; mysids are small shrimp (both are crustaceans).

Generally, acute mercury toxicity results in flaring of gill covers, increased respiratory movements, loss of equilibrium, and sluggishness in fish followed by death (Armstrong 1979). Chronic or sublethal exposures to mercury have been shown to adversely impact reproduction, growth, behavior, metabolism, blood chemistry, osmoregulation, and oxygen exchange in marine and freshwater organisms (Eisler 1987).

Studies that have compared fish tissue mercury concentrations to adverse effects show decreased weight, length, and gonad to body weight ratio in Walleye at whole body mercury concentrations of 1.7 to 3.1 mg/kg (ppm) (Friedmann et al. 1996). But no significant effect on body weight ratio was seen in Northern Pike at a muscle concentration of 0.6 mg/kg (Friedmann et al. 1996). Decreased weight and length were observed in Fathead Minnow at whole body concentrations as low as 1.3 mg/kg.

Fathead Minnows with whole body concentrations of 4.5 mg/kg failed to spawn (Snarski and Olson 1982). Rainbow Trout with whole body mercury concentrations of 4-27 mg/kg (muscle 9-52 mg/kg) exhibited decreased appetite and activity followed by death (Niimi and Kissoon, 1994). Reduced growth was observed at muscle concentrations of 12-23 mg/kg (Wobeser 1975). Increased mortality, decreased growth, sluggishness, and deformities were observed in Brook Trout at whole body mercury concentrations of 5-7 mg/kg (muscle 10 mg/kg) (McKim et al. 1976).

Mercury is a potent teratogen. Exposure of Killifish eggs (blastula stage) to inorganic mercury at 0.03 to 0.1 mg/L resulted in a significant proportion of embryos exhibiting cyclopia (Weis & Weis 1977a). Exposure to methylmercury at 0.03 or 0.04 mg/L also resulted in cyclopia in many embryos and defects in the cardiovascular system of Killifish (Weis & Weis 1977b).

The impacts of mercury on aquatic life are complex. Mercury affects fish growth and behavior in the Mummichog (*Fundulus heteroclitus*) (Weis and Weis 1989). Fish from polluted Piles Creek caught fewer shrimp and had higher brain mercury (mean 0.116 μg/g) levels than fish from a "clean" environment (Tuckerton, NJ) (mean 0.032 μg/g). They were also more susceptible to crab predation. Tuckerton fish raised in Pile Creek water for three weeks showed impairment of capture ability and increased brain levels (Smith and Weis 1997). Embryonic and larval exposure as low as 5 μg/L altered the swimming behavior and increased susceptibility to predation of Mummichogs (Weis and Weis 1995a). The prey-capture ability of the larvae was also impaired initially but gradually improved to control levels after about one week (Weis and Weis 1995b).

F. Toxicity of Mercury to Birds

1. Introduction

Studies of mercury in wild birds can be divided into three categories: eggs and reproduction, liver and other organs, and feathers. In the 1960's great concern over reproductive failures of many avian species prompted studies of various contaminant levels in eggs, particularly in eggs that failed to hatch. Many of these studies were "positive", showing that unhatched eggs had higher contaminant levels (particularly chlorinated hydrocarbons), than hatched eggs and in many cases the contaminants levels were linked to eggshell thinning. Although mercury also causes eggshell thinning, most field studies did not analyze for mercury, and those that did often did not find significant increases in mercury.

Studies of mercury in organs such as the liver were often made on moribund or dead birds to ascertain a cause of death. Widespread surveys of mercury in organs required the killing of large numbers of individuals. This was both inconvenient and undesirable. Hence many studies relied on measuring mercury in feathers. The affinity of mercury for the sulfhydral groups on proteins, accounts for the relatively high concentrations of mercury deposited in growing feathers which are comprised mainly of the sulfhydral rich protein, keratin. A substantial part of the body burden of MeHg is found in feathers (Braune and Gaskin 1987), which, like human hair, have repeatedly proven their value as a means for monitoring mercury concentrations in birds. Thompson et al. (1998) demonstrated the utility of feather mercury in documenting the temporal increase in mercury in the marine environment. Spalding et al. (2000a) found that the mercury levels in the feathers of growing chicks provided a good indication of the mercury dose and helped document the declining mercury contamination in the Everglades soon after curtailing emissions. Likewise, Hughes et al. (1997) showed that feathers were a better indicator of osprey exposure than concentrations in eggs. Burger (1993) provided a global review of mercury in feathers. At any one time up to 80% of the body burden of mercury is in the feathers (Braune and Gaskin 1987), and almost 100% of this mercury is MeHg (Thompson and Furness 1989). Lewis and Furness (1991) showed that about half of a single dose of MeHg was sequestered in feathers.

Feather sampling offers the advantage of being non-destructive (a sample can be removed from living birds with no impact on their subsequent health or survival), they require no special field preservation (i.e. freezing), and they allow comparison with museum specimens, which have been archived for more than a century. The ability to sample feathers without jeopardizing endangered species is particularly advantageous.

2. Temporal Trends

Although the hazards of environmental mercury were already well recognized by 1970, there was considerable speculation regarding the relative contribution of anthropogenic to natural sources for different compartments. Hammond (1971) questioned whether the magnitude of human releases was sufficient to alter the concentration of mercury in the marine ecosystem. Thompson et al. (1998) addressed this question by showing that the mercury content of seabird feathers had increased between 65% and 394% (or 1-4% per year) in five species of North Atlantic seabirds for which pre-1931 and post-1979 feather samples were available.

Based on mercury levels in the feathers of museum specimens, mercury levels in carnivorous birds in Europe were low prior to the mid-20th century and then increased, reflecting the increased anthropogenic (both industrial and agricultural) contribution to the environment. Odsjö (1975) documented the dramatic jump in mercury concentration of Scandinavian Goshawk feathers from < 5 µg/g prior to 1940 to about 20 µg/g after 1940. Peregrine Falcons averaged less than 3 µg/g prior to 1940, jumping to almost 38 µg/g (1964-1966) and declining to 7-17 µg/g in the 1970s (Lindberg and Odsko 1983) as agricultural uses and industrial pollution were curtailed. Smaller differences occur in non-predatory species, such as the Bar-tailed Godwit in the Netherlands where values increased from 0.4 µg/g (1904-1963) up to 2.0-4.9 µg/g (1979-1982).

3. Impact on Birds

The study of mercury levels in avian tissues has played an important role in understanding the dynamics of mercury in the environment. Early in the 1970's, several authors (Gochfeld 1971, Rappe 1973) pointed out that birds, like humans, are at the top of food chains and represent an important early warning system (Hays and Risebrough 1971) for mercury and other pollutants. Several authors in Scandinavia used museum collections to document changes in mercury concentrations over time (see Temporal Trends above).

Birds vary greatly in the amount of mercury in their bodies. In general, birds higher on the food chain, such as fish-eating (piscivorous) waterbirds and bird-eating raptors (hawks and eagles), have higher concentrations of mercury than seed-eating or fruit-eating birds. However, there are exceptions; birds eating grain that had been treated with mercurial fungicides have suffered mercury poisoning.

Most of the mercury in birds is in the form of methylmercury and comes from the diet. Although the consumption of fish is the main human exposure pathway for methylmercury, for the few people who eat piscivorous birds, such as fish-eating seabirds and ducks (e.g., mergansers), this is a potentially significant source of mercury exposure. Granivorous gamebirds such as doves, quail, and pheasants tend to have low mercury levels and pose little threat to human consumers. Even doves that have fed on hazardous waste sites, such as the contaminated lakebed of Par Pond, a Superfund site in South Carolina, have accumulated little mercury (Burger et al. 1997).

Eisler (1987) and Burger and Gochfeld (1997) reviewed data showing that mercury levels of 0.5-6 ppm in eggs are associated with decreased egg weight, malformations, lowered hatchability, and/or altered behavior in various species. Data relating feather levels to hatchability are more sparse, but in some species reduced hatching was observed in the 5-10 ppm range, while in others levels of 40-70 ppm in feathers were associated with lowered reproduction (Finley and Stendall 1978, Eisler 1987). Using 5 ppm in feathers as a criterion level, Burger and Gochfeld (1997) reported that Common Loons were at considerable risk with an average feather mercury level of 10 ppm.

4. Experimental Mercury Poisoning in Birds

Tejning (1967) reported an extensive study on domestic fowl fed an organic mercury compound (methylmercury dicyandiamide) used as a fungicide on grain. Many toxic endpoints were reported, including behavioral endpoints, and an increase in shell-less eggs, a phenomenon observed in NJ and New York Common Terns in the 1960's and early 1970's.

Fimreite and Karstad (1971) reported an experimental study feeding methylmercury-contaminated chicks to captive Red-tailed Hawks. Diet containing 10 µg/g of mercury resulted in death after one month from neurotoxicity. Liver of victims averaged 20 µg/g of mercury. Similarly Goshawks fed chicken averaging 13 µg/g of mercury died between 30 and 47 days (Borg et al. 1970). Toxicity emerged after the second week, included weakness, and loss of appetite and weight. Both studies found axonal changes and loss of myelin.

5. *Mercury in Raptors*

Raptorial birds (hawks, falcons, and eagles) are top predators in their respective ecosystems; therefore they are exposed to the relatively high levels of mercury and other bioaccumulative toxics (such as chlorinated pesticides and polychlorinated biphenyls) in their prey. Some species of hawks and eagles consume mainly mammals, others primarily birds, and a few, such as Osprey, eat mainly fish. Raptors have also been of interest as indicators of environmental pollution, because of the documented population crashes of many species in the 1940-1970 period, attributable primarily to organochlorine pesticides. The recovery of populations of hawks, falcons, eagles, and ospreys subsequent to the reduction in use of these persistent chemicals, attests to the benefits of regulating the release of persistent pollutants to the environment.

Raptors have been studied extensively because of the documented impact of contaminants on survival and reproduction. Although much of this work has been done on European birds, there are a substantial number of North American studies. Borg et al. (1970) attributed the decline of the White-tailed Eagle in Sweden to mercury.

In a study mainly of organochlorines, Snyder et al. (1973) reported on mercury levels in 24 eggs from Cooper's Hawk nests in Arizona and New Mexico. Their level of detection was 0.007 µg/ml of contents, and 23 eggs exceeded that level with a mean of 0.023 µg/ml (approximately 23 ppb).

Elliott et al. (1996) sampled Bald Eagle eggs from six locations along the British Columbia Coast. Geometric mean values ranged from 0.08 µg/g (wet) to 0.29 µg/g, with a maximum of 0.40 µg/g. Bowerman et al. (1994) sampled feathers of adult and young Bald Eagles from six Great Lakes locations and found that feather levels of adults averaged > 20 µg/g at most sites. Although Bowerman et al. (1994) suggested that mercury might contribute to reproductive failure, the major contributor was organochlorines (Grier 1974). In one of the earliest such studies in North America, Fimreite et al. (1970) found relatively low levels of mercury (0.75 µg/g) in livers of the insectivorous Kestrel, compared with moderate levels in Prairie Falcon (1.26 µg/g), and high levels in the carnivorous Short-eared Owl (6.8 µg/g). Table 2.7 summarizes data on concentrations of mercury in raptor species that occur in the United States (even if data were obtained elsewhere).

Table 2.7. Tissue Concentrations of Mercury in Raptors that Occur in the United States (N=1 unless otherwise indicated).

Species	Location	Tissue	Years	Concentration (µg/g)	Reference
Turkey Vulture (C)	California	Feathers	1980s	0.12	Wiemeyer et al. 1986
American Kestrel (I)	NY: Greenport, LI	Liver	1980s	0.22	NYSDEC 1981
American Kestrel (I)	Alberta	Adult liver	1960s	0.75	Fimreite et al. 1970
Peregrine Falcon (B)	Sweden	Feathers	1980s	1.38	Lindberg & Odsjö 1983
Peregrine Falcon (B)	Sweden	Feathers	1980s	0.05-1.7	Lindberg 1984
Peregrine Falcon (B)	**NJ: Barnegat Bay**	**Carcasses, n=3**	**1989-90**	**1.47 wet**	**Day et al. 1991**
Peregrine Falcon (B)	**NJ: Atlantic Coast**	**Eggs, n=12**	**1990-91**	**0.38 wet**	**Frakes et al. 1997**
Peregrine Falcon (B)	**NJ: Delaware Bay**	**Eggs, n=3**	**1991**	**0.01 wet**	**Frakes et al. 1997**
Goshawk (B)	Scandinavia	Feathers, n=16	pre-1940	<5	Odsjö 1975
Goshawk (B)	Scandinavia	Feathers, n=35	1940's	20	Odsjö 1975
Goshawk (B)	Netherlands	Feathers	1966-67	34.7	Spronk & Hartog 1970
Goshawk (B)	Netherlands	Feathers	1966-67	43.3	Spronk & Hartog 1970
Goshawk (B)	S. Finland	Feathers	1980-82	2.7	Solonin & Lodenius 1984
Cooper's Hawk (B)	SW US	Eggs, n=23		0.023	Snyder et al. 1973
Red-tailed Hawk (M)	Alberta	Adult liver		0.48	Fimreite et al. 1970
Northern Harrier (M)	Saskatchewan	Adult liver		0.07	Fimreite et al. 1970
Osprey (F)	S. Finland	Feathers	1980-82	11.6	Solonin & Lodenius 1984
Osprey (F)	NY: Suffolk Co.	Liver		2.4 (wet or dry?)	NYSDEC 1981
Osprey (F)	**NJ: Delaware Bay**	**Eggs, n=11**	**1985-1988**	**Gm=0.09 wet**	**Steidl et al. 1991**
Osprey (F)	**NJ: Atlantic Coast**	**Eggs, n=12**	**1985-1988**	**Gm=0.17 wet**	**Steidl et al. 1991**
Osprey (F)	**NJ:Maurice River**	**Eggs, n=2**	**1985-1988**	**Gm=0.10 wet**	**Steidl et al. 1991**
Osprey (F)	**NJ: Coastal Atlantic**	**Eggs, n=1**	**1999**	**0.15 wet**	**Clark & Niles 1999**
Osprey (F)	**NJ: Maurice River**	**Eggs, n=1**	**1999**	**0.14 wet**	**Clark & Niles 1999**
Osprey (F)	**NJ: Delaware Bay**	**Eggs, n=1**	**1999**	**0.08 wet**	**Clark & Niles 1999**
Bald Eagle (FB)	W. Canada	Eggs	1990-1992	Gms=0.08-0.29	Elliott et al. 1996.
Bald Eagle (FB)	NW Ontario	Eggs	1971-1972	2.49 dry	Grier 1974
Bald Eagle (FB)	MI: Lower peninsula	Adult feathers		Gm=21	Bowerman et al. 1994
Bald Eagle (FB)	MI: Upper peninsula	Adult feathers		Gm=21	Bowerman et al. 1994
Bald Eagle (FB)	Lake Superior	Adult feathers		Gm=22	Bowerman et al. 1994
Bald Eagle (FB)	Lake Michigan	Adult feathers		Gm=20	Bowerman et al. 1994

Bald Eagle (FB)	Lake Erie	Adult feathers		Gm=13	Bowerman et al. 1994
Bald Eagle (FB)	Great Lakes	Juvenile feathers		Gm=3.7-20	Bowerman et al. 1994
Bald Eagle (FB)	**NJ: Gloucester**	**Eggs, n=1**	**1993**	**0.67 (wet)**	**Roberts & Clark 1995**
Bald Eagle (FB)	DE: Bombay Hook	Eggs, n=1	1982	0.04 wet	Wiemeyer et al. 1993
Bald Eagle (FB)	DE: Cool Springs	Eggs, n=1	1983	0.05 wet	Wiemeyer et al. 1993
Bald Eagle (FB)	DE: Bombay Hook	Eggs, n=1	1977	0.03 wet	Wiemeyer et al. 1984
Bald Eagle (FB)	DE: Bombay Hook	Eggs, n=1	1978	0.19 wet	Wiemeyer et al. 1984
Bald Eagle (FB)	DE: Bombay Hook	Eggs, n=1	1978	Replicate, 0.19 Wet	Wiemeyer et al. 1984
Bald Eagle (FB)	**Southern NJ**	**Chick red cells, N=8**	**1992-93**	**0.23**	**Roberts and Clark 1995**
Bald Eagle (FB)	**Southern NJ**	**Chick feather, N=12**	**1992-93**	**2.92**	**Roberts and Clark 1995**
Golden Eagle (M)	NY: Westchester	Muscle, n=1		1.7 (wet or dry?)	NYDEC 1981
Golden Eagle (M)	NY: Westchester	Liver, n=1		2.7 (wet or dry?)	NYDEC 1981

Data obtained on NJ birds is shown in boldface. The letters in parentheses designate the main prey as follows: M=Mammals, B=Birds, F=Fish, I=Insects, C=Carrion. The location of the study is indicated, as is the tissue analyzed. The published concentrations have been converted to micrograms per gram (parts per million). All results for feathers as well as results for most other tissues are reported on a dry weight basis (which is about three times higher than the corresponding wet weight basis). In some cases, the basis cannot be determined from the paper. "Gm" indicated that a geometric mean is reported. This is usually about 20% lower than the corresponding arithmetic mean.

6. *Mercury in Coastal Waterbirds*

In addition to raptors, birds such as pelicans, cormorants, herons, and egrets are also top trophic level predators on fish. Pelicans were among the most prominent victims of the chlorinated hydrocarbons.

Black-crowned Night Herons from Lake Erie were found to average 3.1 ppm mercury in liver and 11.5 ppm in feathers (Hoffman and Curnow 1973). In a California population of Great Egrets showing poor reproduction, liver mercury averaged 6.08 ppm in six birds. There was inadequate data at the time for the authors to draw a conclusion regarding the role of mercury vs. organochlorines in the impaired reproduction (Faber et al. 1972).

Probably no area with mercury pollution has been as extensively studied as the Everglades in south Florida. The MeHg concentrations are elevated in many species of wetland wildlife and have been extensively studied in Great Egrets (*Egretta alba*), one of the top trophic level piscivorous species. Dietary MeHg reduced the appetite and growth rates of baby birds. In the baby birds fed MeHg (Spalding et al. 2000a) at 0.5 mg/kg body weight (comparable to doses encountered in the wild) anemia, feather abnormalities, neurological changes, and immunology damage occurred. At higher doses birds showed gait disturbances. Birds in the wild died at lower doses than laboratory birds, presumably due to multiple stressors (Spalding et al. 2000b). Recent reports (Lange et al. 2000), indicate that the mercury levels in Everglades Egrets has declined in 2000, a rapid response to the reduction in atmospheric inputs to the Everglades.

Herring Gulls from Captree, Long Island, averaged 4.5 ppm of mercury in feathers of males and 3.8 ppm in females. Herring Gulls found dead did not have higher levels in feathers than feathers sampled from live gulls (Burger 1995). However, Herring Gulls from the Mediterranean averaged 8.7 ppm (Lambertini 1982). Additional studies are required to clarify whether the differences are temporal (1970s vs. 1990s) or geographic.

7. Mercury in Seabirds

Marine birds such as albatrosses, shearwaters, petrels, and auks breed on islands remote from local sources of industrial pollution. Their propensity to bioaccumulate mercury and other pollutants serves as important indicators of global mercury transport and marine pollution. The increase in mercury levels in such species during the 20th century has demonstrated that much of the mercury load in the oceans is due to anthropogenic rather than natural sources. (Thompson et al. 1992).

Marine birds appear tolerant of relatively high mercury concentrations and have a lower proportion of their mercury in organic form (Burger and Gochfeld 2001b). Likewise, marine mammals appear to have low susceptibility to mercury (Wang et al. 2001).

8. Mercury in Waterfowl

Considering the popularity of waterfowl hunting and the number of people who eat wild ducks and geese, it is surprising that there have not been more published studies on mercury levels in waterfowl. Vermeer et al. (1973) sampled waterfowl from a mercury-contaminated ecosystem in Ontario, and found a dramatic trophic level effect with mercury concentration in muscle ranging from 0.5 ppm up to 12.3 ppm in fish-eating mergansers. However, some primarily vegetarian species, such as mallards, averaged 6.1 ppm.

9. Mercury in Reptiles

There are few studies of mercury concentrations or effects in reptiles or amphibians. Over much of the southeastern United States, the American Alligator (*Alligator mississippiensis*) is a top level predator in wetlands, feeding on large fish, birds and other organisms. Alligators accumulate mercury in their tissues. In the Everglades, the concentration factors (organ:water) for alligators was about 100 million (Khan and Tansel 2000). Adults had about 50-70% higher mercury levels than juveniles (less than four year old alligators). All piscivourous wildlife in the Everglades are at elevated risk of mercury poisoning, with 100% of alligators exceeding a chronic risk threshold (Duvall and Barron 2000). Alligators had 36 ppm (dry weight basis) mercury in their kidneys (equivalent to about 10 ppm wet weight) (Yanochko et al. 1997). In central Florida, where alligators have been significantly impacted by organochlorine pollutants, mercury levels were low and were considered to have had a negligible impact on reproductive impairment (Burger et al. 2000).

G. Toxicity to Non-Human Mammals

Piscivorous mammalian wildlife are exposed to mercury primarily via the food chain (i.e., consumption of contaminated fish) and bioaccumulate mercury in concentrations higher than those observed in their prey (i.e., biomagnification). Concentrations of mercury in wildlife have been observed at concentrations causing adverse effects in laboratory studies using the same species (U.S. EPA 1997d). Toxic effects from the consumption of contaminated fish have been observed in mammalian wildlife in areas with point sources of mercury emission (U.S. EPA 1997d).

U.S. EPA (1997d) investigated population impacts on piscivorous wildlife and estimated an adverse effect level for methylmercury in trophic level 3 fish (between 0.077 and 0.3 µg/g). This indicates that it is possible that individuals of some highly exposed wildlife subpopulations are experiencing adverse toxic effects due to mercury in the food chain.

U.S. EPA (1997d) examined several wildlife populations including mink, otter, and Florida Panther for the impacts of airborne mercury emissions. They concluded that field data were insufficient to determine whether the mink, otter or other piscivorous mammals suffered adverse effects. However, field data indicated that levels in panthers were high enough to cause toxic effects and contribute to the decline of this endangered animal. In the Arctic, Polar Bears had higher mercury levels in liver and kidney than the Ringed Seals on which they fed (Dietz et al. 2000) and adult bears had higher mercury levels than young ones.

Concentrations of mercury in marine mammals have also been studied. More than 90% of the mercury in marine mammals is in the inorganic form, suggesting that they can readily demethylate MeHg. However, the concentration of methylmercury in the tissues results in accumulation of high concentrations of methylmercury in humans and wildlife consuming these mammals (Clarkson et al. 1984). In another study, average mercury concentrations in the liver of Ringed Seal (*Phoba hispida*) ranged from 1.0 to 230.0 µg/g (wet weight; Wagemann & Muir, 1984). In Gray Whales (*Eschrichtius robustus*) stranded on the Pacific coast, liver mercury concentrations ranged from 9 to 120 ng/g. The concentrations of potentially toxic contaminants in these filter feeding whales was considered low relative to the concentrations in tissues of marine mammals feeding on higher trophic level species (e.g., fish; Varanasi et al. 1993).

An oral dose of 25 mg/kg body weight/day of methylmercury was fatal to Harp Seals in 20 to 26 days (Ronald et al. 1977). Sublethal doses (250 µg/kg body weight daily) adversely affected the cells of the inner ear of Harp Seals, and resulted in liver, kidney, and muscle methylmercury residues of 47.2 –82.5 mg/kg (wet weight; Ronald et al. 1977; Ramprashad & Ronald, 1977). Selenium has a mildly protective effect against the toxic effects of MeHg. Quail fed MeHg in corn-soy vs. a tuna diet, survived well with the latter, which also provided selenium (Ganther et al. 1972), and sodium selenite also protected quail against MeHg (Stoewsand et al. 1974). Marine fish accumulate selenium from sea water (Ganther 1980), which may reduce their vulnerability to the MeHg. Selenium reduces the amount of MeHg that reaches target organs (Komsta-Szumska 1983). Whether the protective mechanism occurs, the level of uptake, tissue distribution, or end organ or cellular toxicity remains to be determined. Recently, Southworth et al. (2000) demonstrated that Largemouth Bass in a Tennessee lake showed a great increase in mercury concentrations after the cessation of selenium-rich effluent into the river. The elimination of the effluent resulted in a three-fold decline in selenium concentrations of fish tissue. In a study of 11 Savannah River fish species, mercury and selenium were strongly positive correlated in only two species (Yellow Perch and Red-breasted Sunfish; Burger et al. 2001a).

H. Wildlife Criteria and Reference Dose

U.S. EPA (1997d) calculated a wildlife criterion for the protection of piscivorous avian wildlife of 61 pg/L (0.061 ppt) for methylmercury. Wildlife criterion is defined as the concentration of mercury in water that protects wildlife (e.g., avian and mammalian) from adverse effects resulting from ingestion of surface waters and from ingestion of aquatic life taken from these surface waters (U.S. EPA 1997d). For protection of piscivorous mammalian wildlife, EPA calculated a surface water wildlife criterion of 50 pg/L (0.05 ppt) for methylmercury. Burger and Gochfeld (1997) identified 0.5 ppm (wet weight) in eggs and 5 ppm in feathers as levels that have been associated with adverse reproductive outcomes.

Wildlife criteria are difficult to determine, and show a range of values, dependent on the form of mercury chosen. Nichols et al. (1999) describe in detail the procedures and uncertainties associated with the estimated Wildlife Criterion Value of 1.3 ng/L (based on total mercury in unfiltered water) published in its Great Lakes Initiative report (1995) and of 0.05 ng/L for methylmercury published in EPA's Report to Congress in 1997.

U.S. EPA (1997d) calculated a reference dose (RfD) for methylmercury for avian species based on the chronic no observed adverse effect level (NOAEL) from studies on mallards. The RfD is defined as the daily intake (in µg mercury/kg body weight per day) that may occur without appreciable risk of any adverse effect on the organism. The value calculated was 26 µg/kg bw/d. However, the comparable value for humans is on the order of 0.1 µg/kg bw/d, suggesting that either the endpoint or procedure for developing wildlife RfD should be reconsidered. However, such a comparison may not be valid since the human RfD is based on studies that involved detailed testing of subtle markers of neurological performance involving interactive communication between tester and subject. Such testing is more difficult with birds. U.S. EPA (1997d) calculated a RfD for mammals of 18 µg/kg bw/d for methylmercury.

U.S. EPA (1997d) concluded that piscivorous avian and mammalian species are the receptors receiving the greatest exposure to mercury. Several avian wildlife populations, including Common Loon, Wood Stork and Great Egret, were examined by U.S. EPA (1997d) for the impacts of mercury emissions. Field data were deemed insufficient to make a determination on whether adverse effects have occurred to these and other piscivorous wading birds due to airborne mercury emissions.

I. Interactions of Mercury with Other Pollutants

Although mercury is one of the most ubiquitous and toxic of the environmental pollutants, it does not occur alone, nor does it necessarily act alone. In tissues of higher trophic level fish, mammals, and birds, methylmercury often co-occurs with other bioaccumulative pollutants, particularly chlorinated hydrocarbons such as PCBs. Polychlorinated biphenyls (PCBs) are also widely distributed in nature and occur as contaminants in fish and other organisms (Rice 1995). Studies on developmental defects in seabirds associated with elevated levels of both mercury and PCBs indicated that an interaction between the two might be causal (Gochfeld 1975). Subsequent research has identified a synergistic mechanism validating this prediction, at least for the central nervous system (Bemis and Seegal 1999). PCBs from fish also cause neurodevelopmental abnormalities in humans (Jacobson and Jacobson 1996; Schantz, 1996). The co-occurrence of PCBs in the Faroe Islands has been suggested as a possible explanation for the neurological effects seen there, although subsequent statistical analysis demonstrated that MeHg was associated with impairment independently of PCBs. The extent to which there may be synergistic or other interactions with PCBs and the endpoints that may be involved should be studied as such information has important public health ramifications. Bemis and Seegal (1999) suggest that the potential for interactions should be considered in the development of fish-consumption guidelines.

On the other hand, selenium has been identified as conferring a possible protective effect against the actions of mercury, at least in certain circumstances. Although selenium is an essential element at low concentrations, it can be highly toxic to aquatic wildlife at high concentrations (Schuler et al. 1990).

J. Summary and Conclusions on Ecological Effects of Mercury

Mercury compounds have been widely distributed in the environment. Due to the discharge and transport of mercury, organism exposure in aquatic and terrestrial ecosystems has resulted in the bioaccumulation of mercury. Mercury, primarily methylmercury, is quickly accumulated by aquatic biota, and methylmercury is the principal form of mercury that causes adverse effects. Biomagnification of mercury up the food chain has been shown, especially in aquatic systems; those predators at the top of the food chain (i.e., piscivorous species) accumulate the highest concentrations of mercury. Mercury accumulation by organisms has resulted in adverse effects ranging from sublethal effects to deaths. Mercury is a teratogen, mutagen, and carcinogen, and causes embryocidal, cytochemical, and histopathological effects (Eisler 1987). Ecosystem-level effects are not well characterized and additional study and data are needed to ascertain the impacts of mercury at this scale. Nonetheless, it is clear that piscivorous species, including birds, fish, and mammals, are especially at risk from the effects of mercury.

EPA developed a Water Quality Criterion (WQC) for mercury for the Protection of Wildlife (1.3 ng/L or ppt) for surface waters of the Great Lakes. In addition, EPA has calculated a surface water wildlife criterion of 0.05 ng/L for methylmercury for protection of piscivorous mammals. These values are well below current Water Quality Criteria for the protection of aquatic life, and indicate that current surface water criteria may not adequately protect wildlife. Therefore, issuance of similar criteria should be considered for protection of wildlife nationally.

K. Recommendations

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, NJ should:

- **Encourage federal agencies to expand existing national research on the ecological effects of mercury, particularly on piscivorous (fish-eating) fish, birds and mammals (particularly marine mammals).**

(From recommendation "M.3." in Volume 1).

Reduce mercury levels in fish and other biota. Mercury concentrations in freshwater and estuarine fish in New Jersey should, at a minimum, be in compliance with the EPA's recent Surface Water Criterion of 0.3 μg/g methylmercury in tissue. This guidance value, aimed at protecting human health, may not be adequate to protect the health of the fish. Therefore mercury levels in surface water and fish tissue should achieve levels protective of aquatic life and of wildlife (the criterion for which is currently under development). Assessing this criterion requires the use of improved analytic methodologies that lower detection levels by at least an order of magnitude. (From recommendation "Q" in Volume 1).

The EPA is encouraged to issue National Water Quality Criteria for the Protection of Wildlife for mercury/methylmercury. NJ should have a comprehensive monitoring program for mercury and other bioaccumulative pollutants in representative trophic and ecosystems to document spatial and temporal trends in the state.

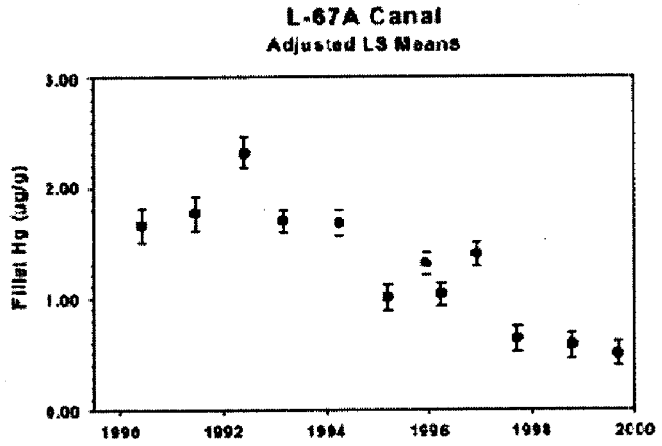
Federal agencies should continue existing national research and monitoring and initiate additional study of the impacts of mercury on piscivorous fish, birds, and mammals (including marine mammals). This should include the examination of ecosystem-level effects and the monitoring of tissue levels in target species to track long-term trends in mercury bioaccumulation. Tissue levels should be compared to national and international mercury reduction efforts and other media measurement (e.g., air, water and sediment) as an environmental indicator of progress.

Chapter 7 - OCCURENCE AND IMPACT OF MERCURY IN NJ'S ENVIRONMENTAL MEDIA

A. Introduction

Mercury in the NJ environment is derived from both natural and anthropogenic sources. Based on various estimates, from 67% to about 80% of the yearly total global input of the mercury in air, water, soil, and food chain is derived directly or indirectly from human activities, both within NJ and elsewhere (Mason and Fitzgerald 1994). The relative contribution of in-state sources vs. regional/global sources to NJ's mercury load has been estimated to be about 67% from regional/global sources (NESCAUM et al. 1998). Other studies suggest that 50% of wet mercury deposition may be accounted for by local or regional sources (EPRI 1994; Bullock et al. 1998). Careful management of mercury sources through reduced use, emission controls, and retirement can reduce the inputs greatly. However, due to the complexity of mercury cycling in environmental media, there will be an inevitable time lag between the reduction of mercury releases to the environment and the lowering of the concentrations in any particular medium such as fish. Some media, particularly air, will reflect the changes more quickly than others, such as sediments. The observations in Florida that reducing mercury emissions from power plants resulted in reduced mercury levels in fish and fish-eating birds in less than a decade is a basis for optimism that mercury reduction will be beneficial quickly (see Figure 2.4). This chapter provides information on mercury concentrations in NJ's environmental media and describes the actions being taken to evaluate environmental mercury.

Figure 2.4. Changes in Mercury Concentration in Tissue of Largemouth Bass in a Florida Everglades Location in Conjunction with Reductions of Emissions of Mercury from Local Sources.



Mercury in fillets of age-standardized largemouth bass in Everglades Canal L-67 (Lange et al., 2000). Adjusted least square means.

B. Mercury in Air

Several studies from various parts of the world have measured gaseous mercury in air in the range of 1 to 6 ng/m^3 (ATSDR 1999a; Fitzgerald 1995) with higher levels measured near specific sources (ATSDR 1999a). In the Report to Congress (USEPA 1997a) a value of 1.6 ng/m^3 was used to represent background concentrations of elemental mercury in the air. There are no reliable measurements of mercury in NJ's air that can be considered representative of the state background.

1. Air Deposition Studies

The Northeast Mercury Report (NESCAUM et al. 1998), using an EPA dispersion model (USEPA 1997a), estimated that deposition in NJ exceeds 30 μg/m^2/year. Research conducted by the NJDEP Division of Science, Research and Technology (Stevenson et al. 1995) found that mercury levels in precipitation and air are elevated above background in certain regions of the state. Levels measured ranged from 5 to 94 ng/L in precipitation, with the higher values in urban areas and lower values in undeveloped, forested areas. A recently established (1998) air monitoring network, the NJ Atmospheric Deposition Network (NJADN), is beginning to provide data on mercury in ambient air and mercury wet deposition. The NJADN was established to measure the amount of nutrients, organics and metals, including mercury, in particles in air and in rain to assess potential impacts of deposition, particularly on water resources. NJADN sites were chosen to provide data on impacts to sensitive watershed management areas and to help determine the extent of the contribution of out-of-state sources of pollution to deposition in NJ. Only total mercury is being analyzed in the samples collected as part of the network.

The sum of wet deposition and dry deposition gives a total deposition value expressed in units of micrograms per square meter per year (μg/m^2/year). Deposition values can be calculated for wet deposition (rain, snow and fog) by measuring aqueous mercury concentrations (μg/L) and multiplying by the volume of sample collected. Estimation of dry deposition is more difficult and subject to greater uncertainty, and estimates of the contribution of dry to total deposition range from less than 10% to nearly 50%. The concentration of various mercury species in air samples can be used to infer the amount of mercury in dry deposition.

The concentrations of mercury in NJ rain generally range from 8 to 20 nanograms per liter (ng/L), and show considerable intra-annual variability. These temporal fluctuations often appear to be statewide trends, and mercury concentrations in rain at the four sites generally vary over fairly narrow ranges for a given sampling period. Volume-weighted mercury concentrations in rain are highest in summer and lowest in spring, a seasonal pattern that may reflect additional sources of mercury to the atmosphere, higher precipitation amounts in summer or higher mercury oxidation rates in summer. Annual volume-weighted mercury concentrations in NJ ranged from 13 ng/L in New Brunswick to 15 ng/L in Camden. These values are generally higher than those measured at other eastcoast and Midwest locations but are comparable to mercury concentrations in rain measured around the Chesapeake Bay. Annual wet mercury fluxes were broadly similar across NJ and were similar to those measured in Maryland. Although regional sources and meteorology affect the variability of mercury concentrations in East Coast rain, lower concentrations have been noted in rural areas.

Table 2.8. Volume-Weighted Mean Concentration and Annual Flux of Total Mercury in NJ and in Other Eastern States (from Eisenreich and Reinfelder 2001).

Site	Volume-weighted Average (ng/L)	Annual Flux ($\mu g/m^2/yr$)	
NJ			
New Brunswick	13	14	
Jersey City (Liberty Science Center)	15	14	
Pinelands Research Center	12	14	
Camden	15	18	
OTHER SITES			
Chesapeake Bay (1995-99)	15	14	
Baltimore, MD (1996)	20	30	
Lake Champlain, NY/VT (1994)	6	8	
Lewes, DE (1996)	8	10	
Cambria County, South Central PA (1997-99)	10	10	
Tioga County, North Central PA (1997-99)	8	7	
Lake Michigan (1995)	10	8	
Little Rock Lake, WI (1989-90)	6	9	

2. *Summary and Conclusions*

On the basis of these preliminary NJ data from the NJADN, the wet deposition of mercury averages about 15 $\mu g/m^2$/year. This is higher than values reported elsewhere in the east, except for the Chesapeake Bay area and are higher than the national average of 10 $\mu g/m^2$/year (Sweet et al. 1999). Higher deposition rates in industrialized, highly populated areas of the East, such as NJ and the Chesapeake Bay region, suggest that local sources are important contributors to total deposition.

C. Mercury in Ground Water

1. *Introduction*

Drinking water is a direct route of human exposure to mercury. To address this important route of exposure, a drinking water standard or "maximum contaminant level" (MCL) of 2 micrograms per liter [2 µg/L or 2 parts per billion (2 ppb)] has been set by USEPA and adopted by NJDEP for inorganic mercury.

In Southern NJ, mercury has been identified in ground water at many locations. It is estimated that there are approximately 400,000 private wells in NJ serving approximately 1.5 million people (13% of the population). Private wells are required to be tested for a limited number of parameters (not including mercury) when the wells are drilled, but thereafter no regular monitoring is currently required. Some local health departments have adopted ordinances that require comprehensive testing of the well when there is a real estate transfer. As of December 2000, only Atlantic and Ocean Counties required testing private wells for mercury during such transactions. A new private well testing bill has been passed in NJ. The bill will require statewide testing of water from private wells upon the sale of a home. While mercury is not included in the statewide testing requirements, it may be included in counties where prior regional testing has shown it to occur in well water.

2. Improved Analytic Techniques

As with air, improved understanding of low-level mercury concentrations has depended on improved analytical techniques and technology. The standard cold-vapor atomic absorption spectrometry protocol for total mercury in water yields a method detection limit of about 0.1 µg/L. However, pristine ground water can have concentrations of less than 5 ng/L (0.005 µg/L or 0.005 ppb). Therefore, the standard method is not adequate for measuring background levels of mercury.

The Skidaway Institute of Oceanography conducted a joint study with NJDEP to estimate background levels and to identify the species of mercury present in the ground water (Murphy et al. 1994; Windom & Smith 1992).

Water samples from known contaminated areas (n=16) as well as from relatively pristine areas of Southern NJ (n=62) were analyzed using the standard cold-vapor technique, an improved cold-vapor technique and an isotope dilution technique for analysis of total, volatile and reactive mercury species (Hg^{++}). A gas chromatographic method was employed for the determination of organic mercury.

The newer methods were found to be more sensitive than the standard method for characterizing background mercury levels in ground water in the range of 0.001 to 0.040 µg/L (inorganic mercury, probably mercuric chloride, was the predominant form of mercury). Volatile mercury (presumably elemental Hg) comprised approximately 10% of the total mercury. Organic mercury comprised less than 3% of the total mercury.

3. Occurrence and Sources of Mercury in Wells

The mercury in the contaminated wells is presumed to come from anthropogenic rather than natural sources. Data on the mercury concentration in rocks, which are a source of the Kirkwood-Cohansey sediments, and in soils overlying the Cohansey Sand reveal a natural background concentration of approximately 10 ng/g (10 ppb). Moreover, glauconite, the only mineral in the NJ Coastal Plain known to contain mercury, is virtually absent from the Kirkwood-Cohansey aquifer formation. Based on this information and a review of existing literature conducted in 1992, the NJ Geological Survey concluded that the mercury found in private well water in NJ is unlikely to be naturally-occurring (Dooley 1992).

NJDEP has been working with the US Geological Survey on a number of investigations. One of the first exercises to determine potential sources of mercury was to assemble all the available data into one master database. Data for mercury by county as of 1993 presented in Table 2.9. Comparing the data with information from other databases, such as locations of point sources and industries, and using the Geological Information System (GIS), USGS sought to find patterns to the contamination cases in an attempt to offer suggestions as to the sources of the contamination. A report, published in 1997, (Barringer et al. 1997) described six hypotheses to explain the mercury contamination. They were: 1) sampling or laboratory error; 2) atmospheric deposition; 3) household sources such as paint; 4) past use of mercurial pesticides; 5) point sources such as landfills; and 6) constituents of well pumps. While ruling out sampling/laboratory error and consitutents of well pumps, the USGS continues to investigate the other possible sources of mercury to wells.

Table 2.9. Distribution of Total Mercury Concentrations in NJ Wells by County (From Barringer et al. 1997: Reporting on Data Collected from County Health Departments and NJDEP Before 1993).

County	# wells sampled	# wells > MCL of 2 µg/L	Median (µg/L)	Range (µg/L)
Atlantic	1,543	202	0.28	<0.01-34.5
Burlington	6	1	<0.01	<0.01-3.53
Camden	472	21	<0.50	<0.1-21.7
Cumberland	82	9	<1.00	<0.1-14
Gloucester	33	8	<0.20	<0.2-20.6
Ocean	51	19	1.10	<0.2-17
Salem	52	6	0.50	<0.2-42
Total	2,239	266	0.40	<0.01-42

Information on mercury concentrations in private potable well samples is maintained by local or county health departments. Since the 1997 USGS report, additional private wells have been monitored for mercury. Mercury has been detected in additional wells throughout southern NJ. As of 1999, there are approximately 400 wells located in 71 discrete residential areas in the state where at least one well contains mercury above 2 ug/L (see Figure 2.5). Gloucester County has initiated two programs for mercury monitoring. The County Health Department has offered to have any resident's well water tested for mercury. Almost 800 wells have been tested as a result of this program, with approximately 8% showing mercury levels above the drinking water standard of 2 µg/L. In addition to this, Gloucester County is designing an intensive monitoring campaign to sample water from 1000 randomly selected wells around the county. This will represent a random study and should help county officials better delineate the geographical extent of mercury contamination in their county.

Ocean County reports data from over 23,000 wells of which less than 1% contained mercury above the drinking water standard. Sampling of 240 wells in Hunterdon County in northern NJ indicate that mercury is not a problem in potable wells there – there were no exceedances of the MCL. In fact, no mercury was detected in these samples. The method detection limit was 0.04 µg/L .

A second phase of the USGS work (Barringer & MacLeod DRAFT) included analyses of tritium and helium in order to estimate the age of the ground water. Water containing elevated mercury concentrations appears to have been recharged to the aquifer between 10 and 55 years before the sampling date, or from 1938 to 1983. This is important information in that it elucidates the time of contamination to the aquifer. It indicates that the contamination is probably not recent.

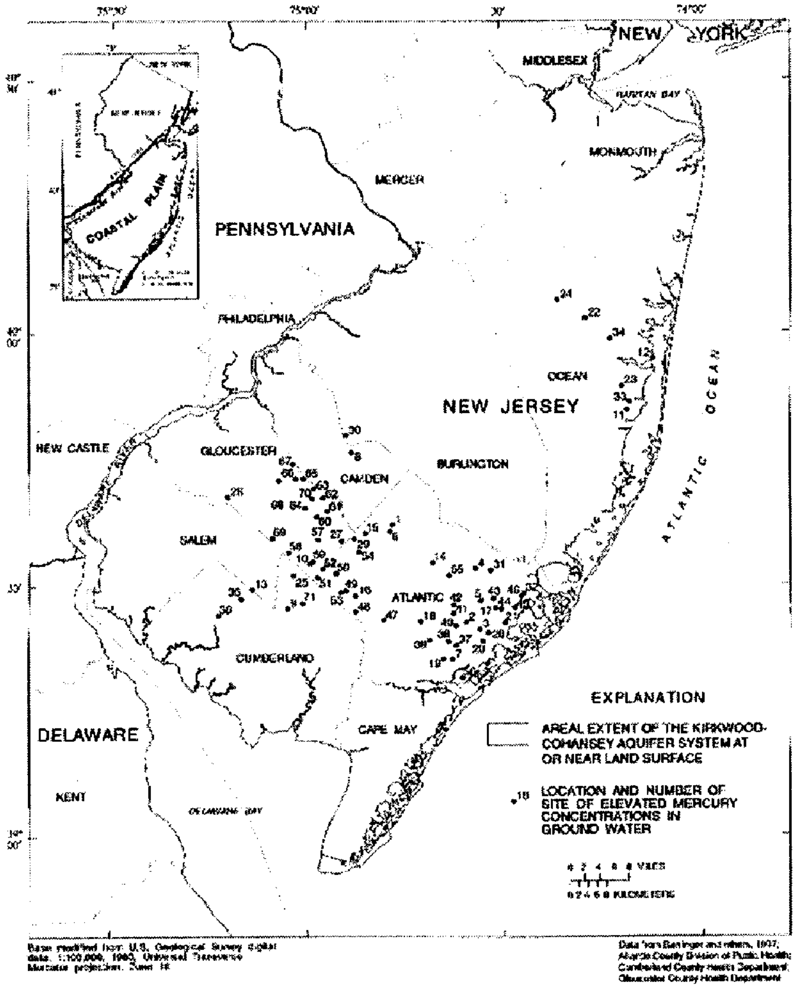


Figure 2.5. Locations of 71 Areas Where at Least One Well Contained Mercury Concentrations Above 2 ug/L. (Inset Map Shows Location of the New Jersey Coastal Plain.)

NJDEP continues to conduct and collaborate in studies investigating the issue of mercury in ground water. In 1998, NJDEP contracted USGS to conduct a two-year, multi-media mercury study to investigate the influence of land use on mercury contamination of ground water and the potential of mercury-contaminated ground water to discharge into surface water systems. The study is currently underway.

4. Reducing Mercury in Private Wells

As a result of finding mercury in well water, NJDEP sought methods of water treatment to install on impacted wells in order to reduce exposure to mercury. A study was performed by NJDEP staff to investigate the efficacy and cost of several types of point-of-entry treatment systems (POET systems) (Sites 1994). Data were collected over a three-year period from six different types of POET systems. Results of the project showed that bi-metallic type units were reliable and consistent at reducing the mercury to levels below the MCL. Wherever feasible, NJDEP recommends that homes with contaminated private wells be connected to community water systems. However, in some instances, this is not feasible, and a POET system is the only way to eliminate exposure to the contaminated water.

5. Summary and Conclusions

Depending on the particular county, approximately 0-13% of wells sampled (selected non-randomly) exceeded the Maximum Contaminant Level (MCL) of 2 ppb for mercury. This contamination appears to be confined to the Kirkwood-Cohansey aquifer and is unlikely to result from natural sources. Mercury in these wells is mostly in the form of mercury salts but small amounts of volatile (probably elemental) mercury have also been detected and raise potential concerns for inhalation during showering. Homes served by wells with mercury levels exceeding the MCL have been connected to community water supplies or supplied with individual point-of-entry (POET) systems.

D. Public (Community and Non-Community) Water Supplies

The NJDEP requires that public water systems, both community and noncommunity, monitor for mercury at different sampling intervals based on the type of water system and the source of the drinking water. At the end of 1997, there were 612 active community water systems (CWS) in NJ. A CWS serves at least 25 year-round residents or has 15 or more service connections (e.g., municipality). The 612 CWS serve approximately 87% of the State's estimated population, with 51% of the population being serviced by surface water systems and 49% by ground water systems. At the end of 1997, there were 4,100 active non-community systems in NJ. A non-community water system generally serves a nonresidential (i.e., an institutional) population. All but three of the NJ non-community systems utilize ground water sources.

Surface water systems monitor annually for inorganics including mercury, and ground water systems monitor every three years for mercury. Systems that exceed the MCL (either in a single sample or with the average of the original and repeat sample) must immediately begin quarterly monitoring. Systems must continue to monitor quarterly until analytical results show mercury to be "reliably and consistently" below the MCL. Ground water systems must take a minimum of two samples and surface water systems must take a minimum of four samples after the last analytical result above the MCL before monitoring frequency is reduced back to the base requirement (i.e., annually for surface water and every three years for ground water systems). The NJDEP Bureau of Safe Drinking Water (BSDW) maintains this data in a database on mercury results reported by community water systems and noncommunity water systems throughout the State.

Over 4,000 public water system samples have been analyzed for mercury since 1993 (Table 2.10). In 2000, only three systems have been issued MCL violations for mercury. A violation for mercury occurs when the mercury level in the original sample, or the average of the original and confirmation samples, is higher than 2 ppb. In general, mercury does not appear to be a problem in community or noncommunity water systems in NJ.

Table 2.10. Mercury in Public Water Supplies (Based on Data From 1993 to 2000).

	Community Water Systems	Noncommunity Water Systems
Total number of systems in NJ (as of end of 1997)	612	4100
# samples with mercury detections	383	185
# systems with mercury detections	169	133
# systems with mercury > 2 µg/L in at least one sample	11	13
Average of detected levels, µg/L	0.76*	1.0*
Median of detected levels, µg/L	0.40*	0.33*
Range of detected levels, µg/L	0.1 – 8.0	0.04 – 10

**Detection limits for mercury during the time period ranged 0.04 to 2 ppb.*

E. Mercury in Surface Water

1. Introduction

Before 2001, Surface Water Quality Criteria applicable to NJ for mercury for freshwater were 2.1 µg/L (acute ecological effects; as dissolved Hg) and 0.012 µg/L (chronic ecological effects based on 30 days; as total recoverable Hg). For saltwater, the criteria are 1.8 µg/L (acute; as dissolved Hg) and 0.025 µg/L (chronic; as total recoverable Hg). The NJ human health criterion for total mercury in freshwater is 0.14 µg/L. Currently, there are no sediment criteria available for NJ. In January 2001, the US EPA announced a new surface water criterion for methylmercury based on fish tissue concentrations of 0.3 µg/g. The corresponding concentration of mercury or MeHg in water is based on waterbody-specific modeling of chemical conversion, uptake and bioaccumulation (US EPA, 2001). NJ has not yet developed an approach for applying this fish-based criterion to the corresponding concentration of mercury in any specific waterbody. Therefore, in this report, comparison will be made to the former criteria.

2. Freshwater

The Ambient Stream Monitoring Network (ASMN) has operated cooperatively by NJDEP and USGS since the early 1970's. Until 1997, mercury data were collected on a rotating schedule at two-thirds of the 79 stations each year. In 1995, modified Clean Methods sampling techniques were implemented, resulting in improved data quality. In 1997, the number of sampling stations was increased to 115, with mercury sampled once a year at each of 40 stations (two per Watershed Management Area) selected at random from the set of approximately 820 benthic macroinvertebrate monitoring stations located in freshwater streams. In addition, in 1998, the NJDEP began monitoring 50 stream segments or estuarine areas identified on the basis of measured or modeled exceedances of applicable surface water quality criteria for mercury (NJDEP 1998). At these locations, Clean Methods techniques are used for sampling total recoverable and dissolved mercury for three consecutive days under stable baseflow conditions. Data for these locations are currently being assessed and are not reported here. The data for mercury for 1990 - 2000 are summarized in Table 2.11.

a. Summary and Conclusions

Although the data are somewhat difficult to interpret due to changes in the number of sampling locations as well as changes in the detection limit, it appears that the occurrence of elevated mercury in NJ streams has decreased since the 1990-1994 period. However, with the current data, it is not possible to assess the potential for ecological impact relative to chronic effects on aquatic life.

3. Estuarine and Marine Waters

The coastal waters of NJ are represented in three National Estuary Programs: NY-NJ Harbor Estuary Program and the Bight Restoration Plan (HEP), Delaware Estuary Program (DELEP), and the Barnegat Bay Estuary Program (BBEP). Both the HEP and DELEP have Comprehensive Conservation and Management Plans (NJDEP 1996). In the NY-NJ Harbor Estuary, mercury exceeds the water quality criterion (for protection against chronic ecological effects) of 0.025 µg/L virtually throughout the estuary (NJDEP 1999). The new EPA Surface Water Criterion for methylmercury (human health) has not yet been applied to NJ waters.

Table 2.11. Number of Stream Samples Exceeding Various Criteria Values.

Sampling Period	Number of Stations Sampled	Percent of Stations Exceeding the Chronic Aquatic Life Surface Water Criterion (0.012 µg/L total Hg)	Percent of Stations Exceeding Human Health Surface Water Criterion (0.14 µg/L total Hg)	Percent of Stations Exceeding the Acute Aquatic Life Surface Water Criterion (2.1 µg/L dissolved Hg)
1990-1994	79	not reported	20%	not reported
1/95-9/97	81	[a]	6%	0%
10/97-10/00[b]	114 (82 stations evaluated with method detection limit = 0.1 µg/L)[b]	[a]	0% [c]	0%

a. Samples were analyzed as total recoverable mercury and the method detection limit was 0.1 or 0.3 µg/L. Therefore, the chronic aquatic life criterion could not be evaluated.

b. The method detection limit for the period 1998-1999 was 0.1 µg/L. The method detection limit during 2000 was 0.3 µg/L.

c. Based on 82 stations sampled in 1998-1999 with a method detection limit of 0.1 µg/L

The NJ Harbor Dischargers Group (NJHDG), comprised of eleven sewerage authorities in the Harbor area, prepared a report entitled "Summary of the Phase I Metal Sampling and Analysis Program for the NJ Component of the NY-NJ Harbor Estuary Program" (Marsh

1996, with supplement). The report for the Hackensack River below Oradell Dam, the Passaic River below the Dundee Dam, Newark Bay, Raritan Bay and the Raritan River below Fieldsville Dam indicated that all of these waterbodies are "water quality-limited" (higher than or close to the water quality standard) for mercury. Most of the load is from unidentified sources and may be due to atmospheric deposition. Phase 1 of this study consisted of twelve sampling events and included three wet weather events and two tidal cycle events (wet weather is defined as a rain event with more than 0.25 inch of precipitation; tidal cycle sampling involved the collection of four samples over the course of one tidal cycle). Data from the Phase I metals sampling program (see Table 2.12) showed that mercury levels did not exceed the water quality standard (WQS) for chronic ecological effects (0.025 µg/L) in Raritan Bay but the standard was exceeded on four different occasions in the Raritan River (GLEC 1996). For Newark Bay, the Hackensack, and Passaic Rivers, the mercury WQS was exceeded on all but four sampling dates: Newark Bay had exceedances of the WQS on 10 of 12 sampling dates and both the Passaic and Hackensack Rivers had exceedances on 11 of the 12 sampling dates. The mercury levels in the Passaic River were 15-35 times higher than the WQS (GLEC 1996) (Table 2.12).

The NJ Toxics Reduction Workplan, part of the HEP program, includes monitoring the loadings of suspended sediments and certain pollutants, including mercury, at the head-of-tide of major tributaries to the Harbor, within the tidal reaches of major and minor tributaries to the Harbor, and within the Newark Bay complex. These data will help locate significant local point sources of mercury such as combined sewer outfalls and municipal wastewater plants.

Table 2.12. Total Mercury Concentrations at Five Sites in the NY-NJ Harbor Estuary, June 15 through December 13, 1995 (GLEC 1996).

	Raritan Bay	**Raritan River**	**Newark Bay**	**Hackensack River**	**Passaic River**
Range (µg/L)	0.003-0.012	0.006-0.042	0.015-0.127	0.005-0.235	0.003-0.878
Mean (µg/L) ±S.D.	0.007±0.003	0.018±0.012	0.069±0.038	0.086±0.068	0.250±0.256
# Samples Exceeding 0.025 µg/L / Total # Samples	0/12	4/12	10/12	11/12	11/12
Percent of Samples Exceeding 0.025µg/L	0	33%	83%	92%	92%

A 1984 survey of water quality in streams of Logan Township in Gloucester County, tributaries of the Delaware River, as defined in the Delaware Estuary Program, indicated that mercury concentrations were ≤0.1 µg/L. This exceeds the marine criteria for chronic ecological effects of 0.025 µg/L and the freshwater criteria for chronic ecological effects of 0.012 µg/L (Hochreiter and Kozinski 1985). The total loading of mercury to the water column of the Delaware Estuary is approximately 10,000 kg/yr (11 tons/yr) (Versar 1994: NJDEP 1996). Of the percent of total loading by toxic substances into the Delaware Estuary, mercury represents 0.9%. Of this, greater than 75% of percent loading of mercury by source is estimated to be due to atmospheric deposition (Sutton et al. 1996; Frithsen et al. 1995).

4. Potential impact of new dam construction in NJ on surface water mercury

Reservoir construction is known to increase available mercury, presumably by converting soil with trace amounts of inorganic mercury to sediment, in which biomethylation occurs, and/or as a result of increased bacterial activity following inundation (Gilmour & Capone 1987). This yields methylmercury which can biomagnify in the newly created aquatic food chain. The age of reservoirs is an important determinant of mercury levels, with younger impoundments having elevated mercury concentrations.

Consistent with these observations, a study in NJ by the Academy of Natural Sciences (ANSP 1994) found that, after adjusting for fish length, pH, and type of waterbody, mercury concentrations were higher than predicted in fish collected from recently filled reservoirs (i.e., Manasquan and Merrill Creek reservoirs) than from other water bodies. Lower than predicted fish mercury concentrations were observed in small impoundments (e.g., Cooper River Park Lake, Newton Lake), small lakes, especially in the Coastal Plain portion of the State, and tidal sites (Delaware River above Camden, Rancocas Creek and Big Timber Creek).

5. Summary and Conclusions

In the Hudson-Raritan Estuary, the mercury levels in the water column were found to exceed (or nearly exceed) the ambient surface water quality criterion. Recent sampling has shown that while mercury did not exceed the water quality criterion in Raritan Bay, the mercury water quality criterion was exceeded in the Raritan River, Newark Bay and the Hackensack and Passaic Rivers. Mercury levels were 15-35 times higher than the water quality criterion in the Passaic River. In the Delaware Estuary there were also exceedances and it is estimated that 75% of the mercury comes from atmospheric deposition.

F. Mercury in Sediments

1. Freshwater Sediments

Sediment concentrations of mercury in isolated lakes subject only to long range atmospheric sources of mercury have mercury concentrations in the range of 0.04-0.24 μg/g (ATSDR 1999a). These values provide an estimate of the background sediment concentration in North America.

Some NJ lakes have been analyzed for sediment mercury concentrations. In Monmouth County, the local health department sampled nine lake sediments. The range of median sediment mercury concentrations reported was 0.07 -0.09 μg/g (ppm) (NJDEPE 1993). The average mercury concentrations in sediments of three lakes in NJ were 0.13 ± 0.05 μg/g (ppm) (Lake Assunpink), 0.21 ± 0.01 μg/g (Mountain Lake) and 0.35 ± 0.07 μg/g (Parvin Lake) (Stevenson et al. 1995). Thus, the mercury concentrations in sediment of this limited sample of NJ lakes and streams are generally in the range of the North American background. Nonetheless, the sediments of Mountain Lake and Parvin Lake are near the lower end of the range where ecological effects might be expected (Stevenson et al. 1995).

Sediment levels of mercury are monitored every three years as part of the NJDEP's Ambient Stream Monitoring Network (Fig. 2.4) and reported in the USGS Water Resources Data Reports. The data from this network have been used to assess the quality of freshwater streams and sediments. Table 2.13 summarizes information on mercury concentrations from this program.

Core studies reveal that surface sediments tend to have higher concentrations of mercury than deeper layers. Other than some limited studies, no comprehensive historic coring has been completed in NJ. However, such a study is now underway. On a national and regional basis, the USGS National Water Quality Assessment (NAWQA) Program is using radiochemical dating of sediment cores to evaluate historical trends in hydrophobic constituents (including mercury) throughout the nation (USGS 1999). These include three sites in NJ: Clyde Potts Reservoir, Orange Reservoir, and Packanack Lake (Krabbenhoft 1999; Van Metre and Callendar 1997.

Table 2.13. Total Mercury Concentrations in Stream Sediments from the Ambient Stream Monitoring Network.

	1990-1997	**1998**
Average, µg/g	0.042	0.034
Median, µg/g	0.02	0.018
Range, µg/g	0.01-1.0	<0.01-0.35
# samples	168	22
# sites	73	22
Detection Limit, µg/g	0.01	0.01

Mercury concentrations in the Orange Reservoir sediment core were approximately 1 µg/g at the bottom (oldest portion) of the core; concentrations increased after 1951 to a current level of 5µg/g. The Clyde Potts Reservoir showed highly variable concentrations at the bottom of the core, while the remainder of the core was not; concentrations varied from 0.26 µg/g in 1973 to a maximum of 0.38 µg/g in 1992. Packanack Lack mercury sediment concentrations increased from 0.27 µg/g (1922-29) to a peak concentration of 0.66 µg/g (1944-48), followed by a decrease to current concentrations of approximately 0.45 µg/g.

a. *Point Source Contamination of Sediment*

There are a number of freshwater sediments, known to have become contaminated with mercury from specific discharges. The Pompton Lakes Works (PLW) used fulminate of mercury, $Hg(ONC)_2$ to manufacture explosives, and its discharges have contaminated Acid Brook, which flows through the facility and discharges to Pompton Lake, where it has formed a delta (i.e., Acid Brook delta). Acid Brook delta sediments have maximum levels of mercury of 1,450 ppm. This is discussed in more detail in Chapter 8, Sec. B.

b. *Summary and Conclusions*

Compared to surface and ground water, the database on mercury in freshwater sediments is very sparse. Based on these limited data, mercury levels in lake and stream sediments in some locations appear to be within the range of North American background. However, at some locations where specific mercury discharges have occurred, mercury levels in sediment greatly exceed background levels. Additional assessments are needed in terms of historic and current levels of mercury loadings to the sediments/soils on a statewide basis with a comparison to regional and local sources of mercury loadings.

2. *Marine and estuarine sediments*

a. *New York-NJ Harbor Estuary*

Data from the NY-NJ Harbor Estuary Program demonstrated that mercury exceeded the water quality criterion virtually harbor wide (NJDEP 1996). Mercury levels in sediments of the estuary exceed the NOAA Effects Range - Median (ER-M) Value of 0.71 µg/g (the level observed to cause adverse effects in biota with a 50% incidence). Mercury exceeds this value by ten times or more in the Hackensack River, Arthur Kill, and Newark Bay. Whereas undisturbed sediments may be a sink for mercury, dredging and other disturbances contribute to resuspension of contaminants in sediments, possibly providing the opportunity for residual inorganic mercury to be methylated and enter the food chain.

The HEP indicated that municipal and industrial discharges of mercury in the Harbor are thought to contribute only a small portion of the total mercury load (NJDEP 1996). One or more large unidentified sources of mercury appear to account for most of the mercury deposition in the Harbor. Therefore, the HEP is attempting to track down the sources of various contaminants including mercury. The HEP CCMP (NJDEP 1996) committed to taking remedial action at selected contaminated sediment sites, including the Passaic River Study Area, and recommended assessment of additional areas of highly contaminated sediments in the Estuary.

Data from the 1995 Phase I sampling program conducted by the NJ Harbor Dischargers Group, indicate that sediment mercury concentrations in the Harbor varied among the five sites (Raritan Bay, Raritan River, Newark Bay, Hackensack River and Passaic River) with concentrations of mercury in the sediments ranging from 0.076-4.81 μg/g. The mercury concentrations were lowest in the Raritan River and highest in the Hackensack River (GLEC 1996).

On a regional basis in the Hudson Raritan watershed, the HEP, in coordination with EPA, completed a R-EMAP (Region Environmental Monitoring and Assessment Project) on baseline sediment quality of various basins within the Harbor (Adams et al. 1996). Surface sediment contaminant concentrations, two sediment toxicity tests (*Ampelisca abdita* and *Microtox μ*), and benthic macrofaunal community structure were measured at 168 sites during 1993-1994 in six sub-basins (Newark Bay, Lower Harbor, Upper Harbor, Jamaica Bay, western Long Island Sound, and the NY Bight Apex).

At least 75% of the Harbor area exceeded the lower range for possible effects on biota (ER-L) and 34% exceeding the ER-M for mercury in the sediments. Newark Bay was the most contaminated sub-basin, with 92% of its samples exceeding an ER-M concentration and 49% of its area showing a toxicological response (Adams et al. 1996). Based on comparisons with EPA's EMAP data from the Virginia Province during 1990-1993 (coastal area from Cape Cod to and including Chesapeake Bay), samples from the Harbor area represent 69% of all samples exceeding the ER-M, even though the Harbor contributed only 4% of the sediments sampled in the Virginian Province (Adams et al. 1996).

There are several sites in the NY Harbor where sediment contamination originates from specific industrial discharges of mercury. Berry's Creek in the Hackensack Meadows is highly contaminated by discharges from the former Ventron plant. Pierson's Creek located in Newark has been highly contaminated with a number of contaminants including mercury from the Troy Chemical site (both are described in more detail in Chapter 8, Section B). Average concentrations of mercury in surface sediments along the six mile reach of the Passaic River study area (including the Diamond Alkalai Superfund Site, were 2.1 ppm (452 samples) with a range of 0.005 to 15 ppm (NOAA 1999). In contrast, sediments at 0.5 - 6 meters depth exhibited a higher average concentration (9.4 ppm) and range (0.11 ppm to 29.6 ppm). These average mercury levels greatly exceed sediment benchmarks for ecological effects (ER-M of 0.71 mg/kg) thereby posing a high risk of adverse effects to aquatic biota.

The NJ Toxics Reduction Workplan (NJDEP 1999), part of the HEP program, includes ambient monitoring of the loadings of suspended sediments and chemicals of concern, including mercury, at the head-of-tide of major tributaries to the Harbor, within the tidal reaches of major and minor tributaries to the Harbor, and within the Newark Bay complex. These data will help identify those tributaries where upstream, major and minor tributary sources contribute significant loadings of chemicals of concern. The fate and transport of suspended sediment and contaminants will be evaluated. A longer-term effort that includes monitoring to assess mercury partitioning and fate, reassessment of loads and appropriate modeling, is needed.

a. Delaware Estuary

The Delaware Estuary Program (DELEP) report, "The Scientific Characterization of the Delaware Estuary" (Sutton et al. 1996) indicates that "...urban runoff, point sources, atmospheric deposition, and ground water all contribute significant amounts of mercury to the estuary". The total input of mercury is approximately 10,000 kg/year (ca. 11 tons/year; Frithsen et al. 1995). The significant sources include atmospheric deposition (80%), urban runoff (10%) and point sources (10%) (Frithsen et al. 1995).

The DELEP identified mercury on its preliminary listing of toxic pollutants based on sediment contamination and possible exceedances of chronic aquatic life water quality criteria; 24 point source discharges were listed as possible sources along with unidentified nonpoint sources. Costa and Sauer (1994) reported that sediment samples obtained in July 1971 between River Miles 80 and 115 (approximately Brandywine Creek north to the Rancocas Creek) ranged from < 0.20 to 0.5 ppm, all exceeding the ER-L. Their data is shown in Figure 2.6.

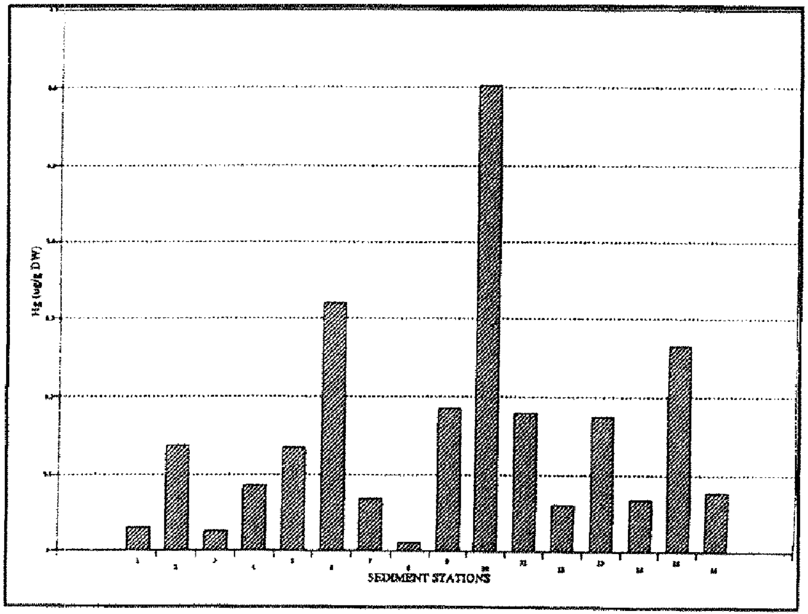


Figure 6-2. Sediment mercury concentrations in ug/g dry weight. Source: from Costa and Sauer (1994).

Provisional data from the Mid-Atlantic Integrated Assessment (MAIA) of sampling locations in Delaware Bay and vicinity in 1997 indicated that most of the lower Delaware Bay had mercury concentrations below the ER-L of 0.15 µg/g (dry wt) while concentrations from Camden northward ranged up to 1.88 µg/g .

b. Summary and Conclusions

In estuarine systems, elevated levels of mercury are found throughout the sediments of the Hudson-Raritan Estuary and in the upper Delaware Estuary. In addition, there are well-documented sources of site specific mercury contamination in estuaries. Mercury in water, sediments, and biota in these estuaries has been identified as a chemical of concern and the NY-NJ HEP is conducting extensive monitoring as part of the Toxics Source Reduction Plans in NY and NJ to address this problem. At least 75% of the NY-NJ Harbor sediments exceeded the lower concentration corresponding to a presumed threshold for effects on biota (ER-L), and many exceeded the ER-M as well.

G. Mercury in Soil

A study of concentrations of contaminants in NJ soils was carried out to support hazardous site cleanup efforts (Fields et al. 1993). The study provides data on the soil concentration of mercury by land use and soil type and is assumed to be reasonably representative. A total of 80 soil samples was collected throughout the state. Thirty-five of the samples were collected from rural, undisturbed areas of the state, and 37 samples were collected from urban (19) and suburban (18) parks in areas representing a broad range of population densities. Several additional samples were collected from golf course greens (5) and agricultural land (3). Table 2.14 shows the results for total mercury.

Table 2.14. Background Concentration of Total Mercury in NJ Soils.

Land or Soil Type	Minimum, mg/kg (µg/g=ppm)	Median, mg/kg	Maximum, mg/kg	Citation
Urban	< 0.01	0.31	2.71	Fields et al. 1993
Suburban	< 0.01	0.06	0.19	Fields et al. 1993
Rural	< 0.01	< 0.01	0.26	Fields et al. 1993
Golf	1.40	5.00	7.70	Fields et al. 1993
Farm	< 0.01	< 0.01	< 0.01	Fields et al. 1993

For comparison, Table 2.15 shows background soil concentrations of mercury reported in other states and the corresponding clean-up standards (levels above which remediation is required). Soil clean-up levels vary from state to state, depending upon the basis for criteria development, and many states differentiate between residential land use standards and industrial/commercial standards.

Table 2.15. Background Soil Concentrations of Mercury by State and Their Corresponding Clean-up Levels (mg/kg=µg/g=ppm).

	Mercury ppm (mg/kg) background	Clean-up level for mercury (mg/kg)
Arizona	0.1	*
California	0.26	*
Connecticut	*	*
Delaware	0.2-0.3	7.8 (residential) 610 (nonresidential)
Georgia	0.5	0.5
Idaho	*	Background
Illinois	<0.01-1.67 (0.11 mean; 0.06 median)	23 (residential) 610 (industrial/commercial)
Kentucky	0.5	*
Massachusetts	0.3	20
Mississippi	*	24

Missouri	*	17
Montana	0.05-0.18	*
NJ	<0.01-2.71	14 (residential)
New York	0.001-0.2	*
Oregon	*	80
Rhode Island	*	23
Vermont	0.876±0.457	*
South Carolina	*	6.7 (residential) 180 (nonresidential)
Texas	*	0.2
Washington	0.02-0.13	*

* Information not available or not known.

1. *Summary and Conclusions*

It appears that, except for golf courses, background soil concentrations of mercury in NJ are generally low, with levels in urban areas higher than those in suburban and rural areas. Based on sparse data, the highest levels in areas not specifically considered to be contaminated sites appear to occur in golf course soil. This may reflect historical use of mercury-containing pesticides. Although comparisons are difficult, background mercury levels in NJ soil appear to be roughly comparable to background levels measured in other states.

Recommendations

Consider establishing the mercury-contaminated sites in the Berry's Creek area as an Environmental Research Park, patterned on the National Environmental Research Park system. This could serve as a resource for studies and monitoring of the complex processor governing the fate and transport of mercury in both the terrestrial and estuarine environment (from Recommendation M.5 in Volume 1).

Expand and maintain a statewide ground water monitoring program for mercury (from Recommendation O.1. in Volume 1). Additional private wells should be sampled for mercury and the samples should be speciated to determine the occurrence of volatile (elemental) mercury. In-house sampling should be undertaken to determine the actual exposures to volatile mercury from showering.

Upgrade procedures used in all monitoring programs to include state-of-the-art analytical methods to provide lower detection limits for mercury and mercury speciation (from Recommendation M.1. in Volume 1). Data on mercury concentration and occurrence in NJ freshwater streams should be generated, compiled and reported as direct numerical values rather than as categorical exceedances so as to provide the greatest utility in interpretation. Data analysis should be expanded to allow assessment of the potential for chronic impacts on aquatic life.

The sampling of NJ waters should be continued and expanded using methodologies that are appropriate for comparison to the water quality standards for protection of aquatic life and for human health.

Since sediment is the crucial environment in which biomethylation takes place, research should focus on understanding and possibly modifying the processes in different kinds of NJ waters.

The Ambient Stream Monitoring program should be continued and a subset of samples should have mercury speciation performed. A lake monitoring network should likewise be established.

Establish a monitoring network for marine and estuarine sediments in the NY-NJ Harbor Estuary as well as in other NJ marine and estuarine waters.

Chapter 8 - IMPACT OF MERCURY ON NJ'S ECOSYSTEMS

A. Introduction

Determining the impact of mercury or any contaminant on ecosystems is challenging. At high concentrations, some organisms may be severely impacted. At lower concentrations, however, the effects are often subtle and may require years to identify. Moreover, there can be multiple contaminants that co-occur, and identifying the influence of any single contaminant, much less its interactions with other contaminants, can be very difficult. Nonetheless, by combining data from a variety of sources, it is often possible to identify ecosystems or ecological resources that are at risk.

This section examines the levels and impacts of mercury on biota and ecosystems of NJ. NJ studies have played a prominent part in understanding mercury contamination and effects on a national basis. However, it will be apparent from this chapter that there remain many gaps in our knowledge.

B. Impacts of Mercury on Specific NJ Sites

There are a number of NJ hazardous waste sites with sufficiently high mercury levels that impacts on local ecosystems can be identified or anticipated. The NJDEP Site Remediation Program does not currently have a database of contaminated sites which can be sorted by contaminant. However, an informal screening of active sites indicates that the levels and extent of mercury contamination are highly variable. Mercury contamination ranges from limited amounts of contamination with few or no exposure pathways to ecological receptors (e.g., contamination under a building) to low-level, but extensive contamination (e.g., Passaic River) with multiple receptors. Aquatic systems are the principal ecosystems impacted by mercury contamination at these sites. Terrestrial habitat and wildlife species at many of these sites are somewhat limited due to the prior industrial character of the sites, resulting in fewer ecological receptors and exposure pathways. Several impacted sites are discussed below.

1. Berry's Creek-Ventron/Velsicol Site

Berry's Creek-Ventron/Velsicol Site, located in the Hackensack Meadowlands (Borough of Wood-Ridge, Bergen County), is one of the most heavily contaminated mercury sites in the world. The site is known as the Ventron/Velsicol Site and is listed on the National Priorities List (NPL). This site is an important example of the ecological consequences of mercury releases to an aquatic ecosystem. The primary source of mercury to this system was historical discharges (1930 to 1974) from a mercury processing plant. Testing conducted around 1970 indicated that the plant was discharging from two to four pounds of mercury per day into Berry's Creek (Lipsky et. al. 1980). Mercury contamination (primarily inorganic or elemental mercury) was found to be widespread at the site and included soils on and adjacent to the site, and the surface waters, sediments and wetland soils of Berry's Creek. (See Table 2.16) The Ventron/Velsicol Site has been administratively segregated from Berry's Creek and the Responsible Parties are focusing on remediation of the 38-acre site.

An early concern was the potential for mercury to move from this site into the ecosystem through erosion, ground water transport, volatilization, and biological transformation/uptake. Estimates of the amount of mercury contamination beneath the Ventron/Velsicol site have ranged from 30 tons to 289 tons (Lipsky et al. 1980).

Table 2.16. Mercury Concentrations at the Ventron/Velsicol Site and Berry's Creek.

Media	Maximum Mercury Concentration	Maximum Methyl-Mercury Concentration	% MeHg
Surface Soils	13,800 (μg/g)	0.322 (μg/g)	<.001%
Subsurface Soils	123,000 (μg/g)	-	-
Ground Water	8.2 (μg/L)	0.02 (μg/L)	0.2%
Surface Water	15.6 (μg/L)	0.00287 (μg/L)	0.02%
Berry's Creek Sediment (0-2 cm)	11,100 (μg/g)	0.0098 (μg/g)	<.001%
On-site Ditch Sediment (0-2 cm)	97.8 (μg/g)	0.020 (μg/g)	0.02%
On-site Basin Sediment (0-15 cm)	1,290 (μg/g)	0.126 (μg/g)	0.01%
Discharge Pipe (6-9 inches)	89,162 (μg/g)	-	-

Concentrations of total mercury have been detected historically up to 15.6 μg/L in surface waters of Berry's Creek. This compares with the mercury chronic surface water criterion of 0.012 μg/L. Methylmercury concentrations up to 2.87 ng/L have also been detected. More recent limited sampling indicate dissolved mercury concentrations of up to 0.24 μg/L and total mercury concentrations up to 17.6 μg/L adjacent to the site (Exponent 1998). The maximum total mercury concentration detected is greater than the acute and chronic water quality criteria values for mercury. Dissolved mercury concentrations have also exceeded the NJ chronic criteria. The observed mercury concentration indicates that there is potential risk to aquatic organisms from mercury in the surface waters of Berry's Creek.

Three studies were funded by the NJDEP for the period 1978 through 1980 to examine concentrations of mercury in the plants and animals of the general area (Lipsky et al. 1980). A 1978 study found mercury to range from 0.01 to 0.79 μg/g in Mummichogs (Common Killifish), and 0.30 to 1.9 μg/g in White Perch in Berry's Creek. A survey of nine locations in Berry's Creek in 1978 by the NJ Marine Sciences Consortium (NJMSC) found mercury at an average concentration of 0.08 to 0.32 μg/g in Mummichogs. Additional data collected by NJMSC indicated that the average concentration of mercury was 0.52 μg/g in Berry's Creek Mummichogs. The average concentrations of mercury for Grass Shrimp was 0.09 μg/g (Lipsky et al. 1980).

A summary of other tissue analyses (ERM-Southeast 1985) indicated that 51% of the invertebrate samples contained greater than 1 μg/g mercury with a maximum of 150 μg/g in snail tissue. These are extremely high values for lower trophic organisms. Forty-three percent of the bird tissue samples and 6% of the mammal tissues had mercury levels greater than 1 μg/g.

Seven species of plants were analyzed in Berry's Creek for mercury including Common Reed *(Phragmites)*, Cord Grass *(Spartina alterniflora)*, and Cattail (*Typha)*. Tissue levels exceeding 1 μg/g were widespread in the Berry's Creek area (ERM-Southeast 1985). Rhizome (root-like) tissue generally had the highest concentrations of mercury. Speciation was not performed, but other studies have found elevated MeHg levels in salt marsh vegetation (Windhou and Kendall 1978).

Current data suggest that sulfide (e.g., acid volatile sulfide, AVS) and sediment organic carbon are two important factors controlling the concentration and bioaccumulation of methylmercury from mercury-contaminated sediments. Berman and Bartha (1986) suggested that elevated sulfide concentrations (i.e., HgS) were the cause for low mercury methylation activity in highly contaminated Berry's Creek sediments. Low dissolved oxygen in Berry's Creek indicates anoxic conditions, which favor production of HgS in the sediments. Therefore, the elevated sulfide concentrations in Berry's Creek sediments may be mitigating the impacts of elevated mercury concentrations by minimizing the mercury available for methylation. However, this "equilibrium" could shift if water quality changes. Ongoing studies of these processes are needed.

2. Pierson's Creek -Troy Chemical Company, Inc.

The Troy Chemical Site is located in Newark on an industrial tract that has been active since the early 1900s. Mercury use occurred from 1956 to the late 1980s. Mercury was purchased and reclaimed (via mercury recovery furnaces) for use in the production of organic mercuric compounds such as phenylmercuric acetate, chloromethoxypropyl mercuric acetate, phenyl mercuric sulfide, and phenylmercuric oleates. Pierson's Creek has been grossly contaminated with a number of contaminants including mercury from the Troy Chemical site and other sites in the area. (See Table 2.17) This man-made waterway discharges to Newark Bay just south of the mouth of the Passaic River.

Process discharges from the Troy Chemical site prior to 1965 went directly to Pierson's Creek. Partial treatment occurred from 1965 to 1976 and an on-site wastewater treatment plant was installed in 1976. In 1979 an investigation indicated that an estimated 327 pounds of mercury per day were discharged into the sanitary sewer system. Due to the inefficient primary treatment level of the Passaic Valley Sewage Commission treatment plant at that time, it was estimated that approximately 90% of the mercury were being discharged into Newark Bay with the plant's effluent.

Pierson's Creek has been contaminated with Hg, with maximum concentrations of 607,000 μg/g in sediment, and 886 μg/L in surface water detected by studies conducted in the late 1970's and 1980's. Mercury was detected in 1979 up to 83,200 μg/g in sediment of an adjacent tributary, and a maximum of 25,290 μg/L of Hg was detected in ground water at the Troy Chemical site. More recent data indicates that Hg concentrations are still elevated in all media (Table 2.17).

The impact of this contamination is primarily on the aquatic ecosystem of Pierson's Creek and Newark Bay. The elevated concentrations and mass of contaminants potentially result in toxic impacts on the benthic invertebrate communities. The downstream transport of contaminants can lead to exposure and bioaccumulation by mobile species (e.g., fish) via direct contact and food chain pathways. In addition, cumulative loadings from similar industrial sites result in the widespread distribution of mercury in the surrounding aquatic systems (e.g., Newark Bay).

The City of Newark plans to dredge sections of Pierson's Creek for the purpose of flood control. Dredging has the potential to increase the availability of mercury that is currently sequestered in the sediment. Remediation of the highly contaminated section of the creek adjacent to Troy Chemical is planned but not currently scheduled. Any dredging should include some mechanism for controlling or removing resuspended materials. To date there is essentially no information on either mercury concentrations or impacts on biota in this area.

3. DuPont Chemicals, Pompton Lakes Works

The Pompton Lakes Works (PLW) site is located in Passaic County and was operated by DuPont between 1908 and 1994 for the manufacture of explosives (Exponent 1999). Acid Brook flows through the facility and discharges to Pompton Lake where it has formed a delta (i.e., Acid Brook delta). DuPont has been investigating the site, Acid Brook, and the Acid Brook delta since 1988 under an Administrative Consent Order with the NJDEP. Soil contamination was detected in both on-site and off-site areas affecting both commercial and residential properties. Acid Brook sediments contained elevated levels of mercury. Due to the contamination found, DuPont conducted remediation of on-site and off-site soils, as well as remediation of sections of Acid Brook sediments. Additional remediation is planned in Acid Brook and upland areas.

Table 2.17. Mercury Concentrations in Various Media Associated with Pierson's Creek and the Troy Chemical Company Site.

Media/Location	Maximum Hg Concentration – 1997	Average of Hg Concentrations – 1997	Notes
Sediment: Pierson's Creek – Upstream of Troy Chemical site	138 μg/g	64 μg/g	From EMCON 1998. Data reported from 5 samples.
Sediment: Pierson's Creek –Troy Chemical Site	3,030 μg/g	1,470 μg/g	From NJDEP files. Data reported from 6 samples reported.
Sediment: Tributary to Pierson's Creek by Troy Chemical Site	6,200 μg/g	2,110 μg/g	From NJDEP files. Data reported from 4 samples reported..
Sediment: Pierson's Creek – Downstream of site	5,020 μg/g	1,020 μg/g	Data reported from 11 samples reported..
Soil: Troy Chemical Site	4,300 μg/g	Range: 0.6-4,300 μg/g	Data from 5 on-site sampling locations.
Surface Water: Pierson's Creek	5.2 μg/L	Range: ND – 5.2 μg/L	Data from 7 sampling locations.
Ground Water: Troy Chemical Site	2,500 μg/L	Range: ND – 2,500 μg/L	Data from 5 on-site monitoring wells. 25,290 μg/L reported from 1 well in 1982 (NJDEP files).

ND - not detected

DuPont conducted a Phase I and Phase II ecological study (Exponent 1999) that examined the impacts of mercury contamination in the Acid Brook delta where it empties into Pompton Lake. Sediments in the delta have maximum levels of mercury of 1,450 mg/kg. Mercury concentrations in algal mats, phytoplankton, zooplankton and benthic invertebrates of the delta are much higher compared to presumably unimpacted reference sites in Pompton Lakes. In addition, fish tissue MeHg concentrations were higher in all seven species of fish (e.g., sunfish, white perch, largemouth bass) captured at the delta as compared to the reference area of the lake. The delta serves as a source for the bioaccumulation of mercury within the food chain of Pompton Lake.

When comparing similar sized fish, average mercury concentrations ranged from 27-33 ng/g for reference Pumpkinseed and 71-140 ng/g for Delta Pumpkinseed. A similar trend was observed for Yellow Perch (130 ng/g versus 440 ng/g) and Largemouth Bass (83-390 ng/g versus 200-1,200 ng/g) for various areas of Pompton Lake.

4. Passaic River Study Area

Another type of site that represents more diffuse contamination of an aquatic system is the lower Passaic River. This section of the river has been subject to multiple point discharges from local industry and non-point discharges for the past one hundred years. The Passaic River Study Area consists of the lower six miles of the river and encompasses the area alongside the Diamond Alkali Superfund Site, a former pesticide manufacturing facility located approximately 2 miles upstream of the river mouth (US EPA 1999c).

Several investigations have collected numerous sediment cores along this reach of the Passaic River. Average mercury concentrations in surface sediments (e.g., ≤ 15cm) of the river (452 samples) were 2.1 mg/kg with a range of 0.005 to 15 mg/kg (NOAA 1999). In contrast, sediments at depth (>15 cm to several meters) exhibited a higher average concentration (9.4 mg/kg) and range (0.11 mg/kg to 29.6 mg/kg). These average mercury levels exceed sediment benchmarks for ecological effect (ER-L of 0.15 mg/kg and ER-M of 0.71 mg/kg) indicating potential adverse effects to aquatic biota. Although mercury concentrations may be at a level causing impacts, other contaminants (e.g., dioxin) may be causing equal or more severe impacts (e.g., toxicity) making it difficult to identify specific effects of mercury. This situation is typical of many waterbodies in highly urbanized/industrial areas that have multiple contaminants and sources.

5. Environmental Research Parks

Pioneered by the US Department of Energy in 1971 (USDOE 1994), the National Environmental Research Parks (NERPs) are public lands "open to the researchers for ecological studies and the general public for environmental education". DOE sets aside parts of its large nuclear weapons development sites to study the impact of weapons development, nuclear reactors, and radioactive waste, on surrounding ecosystems. The NERPs address national concern about environmental change, remediation and recovery, and the ability of land to adapt to and recover from contamination. The results from research on NERPs has been used to improve landuse planning, develop site-specific remediation goals and methodologies, and develop an information network for studying biodiversity and managing public lands and improving environmental quality (USDOE 1994).

6. Summary and Conclusions: Impacts of Mercury on Specific NJ Sites

There are a number of sites within the State that are highly contaminated with mercury and which may impact adjacent ecosystems. These include sites with low-level, extensive contamination (e.g., Passaic River) with multiple receptors, and sites with high-level contamination (e.g., Troy Chemical, Berry's Creek). Aquatic systems are the principal ecosystems impacted by mercury contamination at these types of sites. For none of these sites is there adequate characterization of the fate and transport of mercury through the food chain, nor are there adequate studies that would reveal impacts on behavior, biochemistry, reproduction, health, survival, or population dynamics of organisms.

Mercury discharges to the Berry's Creek ecosystem have led to widespread contamination of the soil and sediment in the area. There is evidence of increased bioaccumulation of mercury in proximity to the site. Paradoxically, more severe impacts may occur if water quality improves, thus allowing a greater utilization of the habitat by higher trophic level aquatic species (e.g., fish). Due to the large quantity of mercury in the Berry's Creek ecosystem and the potential for water quality changes and mercury release, it is recommended that additional study and monitoring of this ecosystem be conducted. Characterization of the transport and bioaccumulation of mercury in Berry's Creek and downstream waters is needed to determine the potential future impacts from the site.

C. Mercury Occurrence and Levels in NJ Fish

The bioaccumulation of mercury in aquatic food chains and most specifically its concentration in higher trophic level fish poses a potential ecological impact to the piscivorous biota and to the fish themselves. This section provides an overview of mercury levels in NJ freshwater and saltwater fish, presents the available data on the impact of those levels to the fish and to their predators.

1. Freshwater Fish

Finfish contamination results primarily from bioaccumulation of pollutants through the food chain. Mercury accumulation is widespread across species and trophic levels, with generally higher levels in larger individuals of any species and higher levels in species higher on the food chain. Data are available mainly on species consumed by humans or those classified as endangered or threatened.

Data on mercury in NJ fish are available through research conducted from the late 1970's to the present. Most of the fish research has been conducted in the state's freshwater rivers, streams, lakes and reservoirs.

Prior to 1994 there was no systematic effort to collect data on mercury levels in NJ freshwater fish that could provide a useful statewide picture. Data that had been collected are limited in coverage and do not necessarily focus on fish from higher trophic levels or fish likely to be consumed by humans. Data from the 1970's and early 1980's (Jacangelo 1977; Ellis et al. 1980), which focused on industrialized areas found evidence of significant elevation of mercury concentrations (> 0.1 ppm). Fish from less industrialized areas, of the state had variable levels of mercury (NYDEC 1981; USFWS 1983, 1990), which tended to be moderately elevated for higher trophic level species while remaining low in fish at lower trophic levels.

NJDEP and the Academy of Natural Sciences of Philadelphia study (ANSP 1994, 1999) reported on results of surveys of mercury contamination in freshwater fish for 1992-94 and 1996-97, respectively, from selected waterways throughout NJ (see Table 2.18). These studies were designed to identify the range of mercury levels for selected fish species. The project design targeted gamefish species from waterbodies via a stratified geographic approach. Sampling locations were selected based on mercury point source inputs, importance of angling at the water body, limnological factors favorable for bioaccumulation (e.g., low pH), recently developed impoundments and reservoirs, and availability of targeted fish species. In the 1992-94 survey, a total of 313 fish from 55 waterbodies were collected. The primary fish species analyzed were Largemouth Bass (n=146) and Chain Pickerel (n=62). Other species sampled in lesser quantities were Smallmouth Bass, White Catfish, Channel Catfish, Yellow Bullhead, Brown Bullhead, Lake Trout, Black Crappie, Hybrid Striped Bass, Rainbow Trout and miscellaneous specimens of Northern Pike, Muskellunge and Walleye.

The study focused on medium or large sized individuals of each species, and all samples were composed of a single edible fillet from an individual specimen. In general, the mercury concentrations varied greatly among lakes, fish species, and with the size of the fish.

Table 2.18. Distribution of Mercury Concentrations in Largemouth Bass and Chain Pickerel in New Jersey Waterbodies Sampled in 1992-94 & 1996-97 (ANSP 1994a, 1999).

	Percent of Sampled Waterbodies			
	Largemouth Bass		**Chain Pickerel**	
Average Mercury Concentration for each Species	**1992-94***	**1996-97***	**1992-94***	**1996-97***
<0.07 ppm	0 %	0 %	0 %	0 %
0.08 - 0.18 ppm	16.0 %	20.0 %	6.0 %	25.0 %
0.19 - 0.54 ppm	56.0 %	45.5 %	53.0 %	31.5 %
>0.54 ppm	28.0 %	34.5 %	41.0 %	43.7 %

*1992-94 Data (55 Waterbodies Sampled), 1996-97 (30 Waterbodies Sampled)

Tables 2.18 and 2.19 present a summary of these data for the fish species with the highest mercury concentrations. Among the significant findings from this study are the following:

Mercury concentrations greater than 0.5 ppm and 1.0 ppm (FDA Action Level) were seen in fish from a variety of NJ water bodies. Mercury concentrations generally increased with fish size for most species tested and levels > 0.5 ppm were identified primarily in the larger specimens of Largemouth Bass and Chain Pickerel from several lakes and reservoirs. The highest mercury concentrations (3.0 - 8.9 ppm) were found in specimens of Largemouth Bass collected from the Upper Atlantic City Reservoir. High concentrations were also noted in Largemouth Bass from the Manasquan Reservoir (up to 3.9 ppm) and Union Lake (up to 2.0 ppm). Of the 55 waterbodies sampled, 19 (35%) had at least one Largemouth Bass with > 0.5 ppm mercury and 8 (15%) had at least one bass with > 1.0 ppm mercury.

Table 2.19. Percent of Fish Exceeding 0.5 ppm and 1.0 ppm.

	% Exceeding 0.5 ppm	**% Exceeding 1 ppm**
Largemouth Bass n=146	43% (n=63)	17% (n=25)
Chain Pickerel n=62	56% (n=35)	35% (n=22)
Yellow Bullhead N=9	44% (n=4)	33% (n=3)

The variation of mercury concentration in fish by geographic location probably reflects a number of parameters, including lake morphology, size, and type, as well as variations in pH, and local inputs from industrial activities and wastewater sources. Higher than predicted mercury concentrations in fish were found in recently filled reservoirs and sites from the industrialized northeastern part of the state. Lower than predicted mercury concentrations were observed in small run-of-river impoundments, tidal rivers and small (mainly coastal plain) lakes. Mercury concentrations tended to be higher at sites with lower pH. High mercury concentrations were measured most frequently in Chain Pickerel from low pH (pH 4-5) lakes and streams in the Pine Barrens region and less acidic lakes (pH 5-6) at the edges of the Pine Barrens. All specimens collected from the Pine Barrens sites had mercury concentrations greater than 0.5 ppm, and 70% had mercury concentrations greater than 1.0 ppm, with a maximum of 2.1 ppm noted.

ANSP (1994b) also conducted a separate study of mercury concentrations in fish collected from rivers and lakes in Camden County, NJ in conjunction with Camden County. A total of five river and seven impoundment sites were sampled. Overall, the mercury levels identified were similar to those previously reported in the 1992-3 statewide ANSP study. The highest mercury concentrations were in samples of Largemouth Bass (1.36 ppm) from Marlton Lake and Chain Pickerel (1.30 ppm) from New Brooklyn Lake, where three of the five Chain Pickerel sampled exceeded 0.50 ppm. Levels in catfish and Black Crappie were low to moderate (generally <0.5ppm).

ANSP (1994c) reported on mercury concentrations in fish collected from three northern NJ reservoirs of the Hackensack Water Supply Company. In this study, samples of Largemouth Bass, Smallmouth Bass, Yellow Bullhead and Common Carp were analyzed. Overall, the concentrations of mercury in fish were low to moderate for all species sampled. However, three Largemouth Bass exceeded 0.50 ppm, with the two highest mercury concentrations, 0.82 ppm and 0.78 ppm, identified from Lake Deforest. Samples of Smallmouth Bass from Lake Tappan averaged 0.07 ppm, while Yellow Bullhead and Common Carp had low to moderate levels (average=0.09 ppm and 0.12 ppm).

NJDEP (1995) reported on results of a pilot project that examined a multi-media profile of three NJ rural, freshwater lakes. The lake profile included collections of surface water, sediments, soil, aquatic vegetation and fish at each lake. The three lakes were located in northern (Mountain Lake, Warren County), central (Assunpink Lake, Monmouth County) and southern (Parvin Lake, Salem County) areas of the state. A total of 15 Largemouth Bass samples (individual edible fillet) and 10 samples of Banded Killifish (individual whole body) were analyzed for total mercury concentrations. Levels of mercury in the Largemouth Bass ranged from 0.14 - 0.40 ppm for the three lakes. The average mercury concentrations in Largemouth Bass from Mountain Lake were 0.23 ppm, Assunpink Lake, 0.31 ppm and Parvin Lake, 0.30 ppm. Forage fish species such as Banded Killifish had mercury concentrations ranging from 0.01 to 0.04 ppm for all three lakes. Interestingly, the mercury concentrations in fish and aquatic vegetation followed a similar pattern for each of the three lakes. Data covering additional fish species and water bodies is expected to be available by 2002.

The results of this study identified an increase in mercury concentrations (through bioaccumulation/biomagnification) across trophic levels in all three of the NJ lakes. The mercury concentrations identified in top trophic level fish (Largemouth Bass) were at least six times greater than the levels identified for forage fish (killifish) and at least ten times greater than for aquatic vegetation. The average mercury concentrations for the Largemouth Bass analyzed for this project were comparable to concentrations of mercury identified in other water bodies (ANSP 1994a, 1994b).

ANSP (1999) reported on mercury in freshwater fish collected from 30 additional waterbodies throughout the state in 1996-97. This project complements the 1992-3 screening project and was designed to fill data gaps in the earlier study, develop trophic transfer information, and to provide additional fish data for selected geographic areas. Samples from 258 fish were analyzed, including 58 Largemouth Bass, 58 Chain Pickerel, and 109 fish of other species. Also, 32 composite samples of several species of forage fish were analyzed.

The results of this study were consistent with those of the 1992-3 study. Mercury concentrations showed a general increase at higher trophic levels. Maximum mercury concentrations were generally highest in piscivorous fish such as Chain Pickerel (average=2.30 ppm) and Largemouth Bass (average=1.68 ppm). Among the lower trophic level species, no clear differences were observed between planktonivores (e.g., Golden Shiners) and invertebrate feeders (e.g., the sunfish). Mercury concentrations for bottom feeding species of bullhead and catfish varied greatly by sampling location and region.

The highest mercury concentrations were in fish from the northern portions of the Pine Barrens (Double Trouble Lake, Ocean County), and on the periphery of the Pine Barrens (Willow Grove Lake and Malaga Lake, Salem County and Success Lake, Ocean County). Dwarf Sunfish had elevated mercury levels compared to other species their size. This may partly explain the elevated levels found in Chain Pickerel in the same lakes. High levels were also seen in fish from the northeastern part of the state where several of the rivers have a history of impacts from industrial activities. Average mercury concentrations in Largemouth Bass, Smallmouth Bass and Yellow Bullhead collected from the Pompton River in Passaic County were 1.17 ppm, 0.96 ppm and 0.80 ppm, respectively. The lowest concentrations were seen in samples from the cold water streams and high pH lakes in the northern part of the state, the Delaware River and in rivers of the southwestern part of the state. In general, the mercury concentrations in most catfish (White and Channel) were less than 0.30 ppm, but some individuals had levels > 0.5 ppm. Mercury concentrations in Yellow Bullhead were much higher than in Brown Bullhead in most waters where both species were collected, with Pine Barrens lakes having the highest levels for both.

Three sunfish species (Bluegill, Redbreast, and Pumpkinseed) were low in mercury concentrations in most areas, except for samples collected from the industrial northeast sites. High levels were identified in individual samples of Redbreast Sunfish (up to 0.41 ppm), Pumpkinseed Sunfish (up to 0.78 ppm) and Rock Bass (up to 0.58 ppm) collected from the Pequannock and Pompton Rivers, in Passaic County.

ANSP (1999) also reported a 1995 analysis of mercury in fish for 15 water bodies for which specific health-based consumption advisories were issued on the basis of the 1992-3 mercury screening study. The project included collections of gamefish species from three trophic levels and a forage fish specie. As in the original ANSP (1994a) project, Largemouth Bass and Chain Pickerel were targeted as the top trophic level species, but other top trophic level species, lower trophic level fish, forage fish, and omnivorous bottom dwelling species were also sampled. Overall, the results paralleled the initial 1992-93 ANSP (1994a) findings, where typically, the largest specimen of gamefish sampled exhibited the highest mercury concentration.

a. Summary and Conclusions

Mercury is a widespread and persistent contaminant in freshwater fish collected throughout the state. Concentrations exceeding 1.0 ppm have been found in higher trophic level fish, particularly Largemouth Bass and Chain Pickerel, in about 40% of the tested waterbodies. Some lakes in industrialized areas of the state which are subject to local mercury pollution had fish with elevated mercury levels, but some lakes in unpolluted areas such as the Pine Barrens also had high levels. Mercury concentrations in lower trophic level fish are also elevated and are commonly in the range of 0.2 to 0.5 ppm. Thus many tested water bodies exceed the recent surface water criterion value of 0.3 ppm in fish tissue promulgated by US EPA (2001). Waters impacted by industrial or municipal discharge, poorly buffered waters with low pH (e.g., many in the Pine Barrens), and newly created lakes, tend to have fish with elevated mercury levels.

2. *Saltwater Fish and Invertebrates*

Fishing is a major recreational and economic activity in the estuarine, coastal and offshore waters of NJ. There are an estimated 1.2 million anglers who take about 4.5 million saltwater fishing trips per year, at a value of $1.2 billion. Although the catch-and-release option allows fishermen to enjoy their sport, preserve their resource, and avoid contaminants, the majority of saltwater fishermen eats some or all of their catch or gives it to friends or family. Moreover, upon returning from a successful fishing trip, they may consume fresh fish in large amounts over a period of a few days.

Relatively few data exist on mercury levels in NJ saltwater fish, reflecting the lack of systematic sampling. Ellis et al. (1980) reported the results of a study of metals in aquatic organisms primarily from the estuarine waters along coastal NJ. The data are shown in Table 2.20. A total of 77 species of fish, shellfish and crustacean were collected between 1978 and 1980. Among finfish species, the highest mercury concentrations were identified in eight high trophic level and two lower trophic level species. Samples for this study consisted of a combination of individual (single) edible portions of consumer species and whole body composite samples for lower trophic level samples.

Table 2.20. Mercury Concentration in Selected Saltwater Aquatic Species Collected from
The Lower Hudson River Estuary* (after Ellis et al. 1980).

Sample Type	Species	Average Hg (ppm)
Whole Body	Silversides	2.50
Composite Sample	Soft Clam	2.00
	Blue Mussel	1.90
	Killifish	1.66
Individual Fillet Sample	American eel	2.10
	Striped Bass	1.65
	Bluefish	1.40
	White Perch	1.32
	Summer Flounder	1.16
Composite*	Blue Crab	1.02

** Composite sample of backfin and claw meat from individual specimen*

The USFWS (1990) reported results for a variety of metals, organochlorine pesticides and polychlorinated biphenyls (PCBs) in fish and crabs collected from Deepwater, NJ. Three Blue Crab samples from the Deepwater, NJ site had moderately elevated mercury concentrations. Two of the Blue Crab samples were a muscle/hepatopancreas mixture. These samples revealed concentrations of 0.14 ppm and 0.19 ppm. The other Blue Crab sample was divided into separate muscle (backfin & claw) of 0.19 ppm and hepatopancreas (green gland) tissues with a mercury concentration of 0.13 ppm.

NOAA (Reid et al 1982 and Zdanowicz &Gadboisl 1990) reported on a variety of heavy metal and organochlorine contaminants in four marine fish species (Bluefish, Fluke, Seabass, and Tautog) collected from popular recreational fishing areas along the coast of Monmouth

County and within eight miles of the beach. Samples for metal analyses were composites of fillets from three specimens. The data are shown in Table 2.21. Mercury concentrations for all samples were low and did not exceed 0.11 ppm, and none of the composite fish reached 1.0 ppm. In general, the relative ranking of mercury concentration by species was Tautog = Bluefish > Fluke = Sea Bass. No biological or behavioral features were offered to explain this relationship.

A study by NOAA (Drexel et al 1991) reported on a variety of inorganic and organic contaminants in tissues of American Lobster caught from the New York Bight Apex. A total of 508 lobsters were analyzed for this project. Samples were obtained from commercial lobster fishery operators across a wide area within the New York Bight Apex, including the vicinity of the Mud Dump Site, the Hudson-Raritan estuarine outflow pipe, the Christiansen Basin, and the Hudson Shelf Valley. Samples consisted of composite tissue from five similar size, same sex specimens. A total of 48 muscle (tail) tissue and 48 hepatopancreas tissue and four extruded egg mass tissue samples were analyzed in this project. The remaining lobsters were individually composited and analyzed. All samples were analyzed for organic compounds and ten metals including total mercury. Overall, mercury concentrations for this project did not exceed 0.50 ppm. The maximum composite concentrations of mercury in muscle tissue and composite hepatopancreas tissue samples of five crabs were 0.491 ppm and 0.247 ppm, respectively. Mercury concentrations were below detection limit (<0.004 ppm) in all four of the egg mass samples. Seasonal differences in metal concentrations were observed in hepatopancreas tissue samples. Mercury concentrations in both muscle and hepatopancreas tissues were lowest from specimens collected in the fall (October).

Table 2.21. Mean Mercury Concentrations of Composite Samples by Species in ppm, Wet Weight.

Species	Site A	Site B	Site C	Site D	Site E	Site F
Bluefish	0.10 (5)	0.11 (5)	0.10 (4)			
Tautog	0.09 (5)	0.08 (4)	0.08 (5)			
Sea Bass	0.06 (4)	0.05 (5)	0.05 (5)			
Fluke	0.04 (2)	0.04 (2)	0.04 (3)	0.04 (3)	0.04(2)	0.03(2)

(n)= Number of composite samples per station

NYSDEC (1996) analyzed total mercury concentrations in edible portions of fish, bivalves, crustaceans and cephalopods taken from the New York - NJ Harbor Estuary including four NJ waters: Upper Bay; The Kills (Arthur Kill, Kill Van Kull and Newark Bay); Lower Bay; and the New York Bight Apex. The species of fish collected were American Eel, Atlantic Herring, Atlantic Tomcod, Bluefish, Butterfish, Cunner, Kingfish, Northern Sea Robin, Porgy, Rainbow Smelt, Red Hake, Sea Bass, Silver Hake, Spot, Spotted Hake, Striped Bass, Striped Sea Robin, Summer Flounder, Tautog, Weakfish, White Perch, Windowpane Flounder and Winter Flounder. The bivalves collected were Blue Mussel, Eastern Oyster, Hard Clam, Horse Mussel, Soft-Shell Clam and Surf Clam. The crustaceans were American Lobster and Blue Crab (both muscle and hepatopancreas tissue). The single cephalopod species was Longfin Squid.

Analyses for total mercury were conducted on 545 samples, and mercury was detected (above the minimum detection level of 0.05 ppm) in 422 samples (77.4%). Two individual Striped Bass samples exceeded 1.0 ppm (1.05 ppm and 1.25 ppm). Mean mercury concentrations exceeded 0.5 ppm only in Striped Bass measuring 30 inches or more in total length (the largest size group tested). Individual samples of American Eel, Bluefish, Cunner, Striped Bass, Tautog, White Perch and Blue Crab (muscle meat) approached or exceeded 0.50 ppm. Only Striped Bass and Tautog had average mercury concentrations greater than 0.25 ppm. Non-detectable mercury concentrations (<0.05 ppm) were encountered most frequently in the six bivalve species, and in Butterfish, Winter Flounder, the hakes and American Eel. For most species, there were few differences in mercury concentration among the four locations in the harbor estuary.

a. Summary and Conclusions

Data on mercury levels in saltwater fish in NJ are limited and mainly reflect estuarine rather than marine species. Based on the currently available data, most species have moderate mercury concentrations, averaging less than 0.25 ppm. Striped Bass and Tautog, however, may have mercury concentrations in the range of 0.5-1.0 ppm.

Data from 1980 for the Hudson-Raritan Estuary identified relatively high mercury concentrations in both forage base species as well as top trophic level species, while more recent data revealed only a limited number of samples with elevated mercury concentrations. The reason for and the significance of the apparent decline are uncertain due to insufficient data. These waterways have a current and historical record of municipal and industrial discharge activities and the data indicate that these waterways are still impacted.

D. Impacts of Mercury on NJ Fish

1. Introduction

There are two basic approaches that can be taken to assess the impact of mercury in NJ waters on the fish in those waters. One approach can be referred to as a direct approach. This involves making observations of fish health, survival, and performance as a function of mercury exposure. These observations can be supplemented with studies of health, survival and performance under controlled laboratory conditions in which mercury exposure duplicates that experienced in the environment. The other approach can be referred to as an indirect approach. This involves comparing measured concentrations of mercury in water or in fish tissue to toxicity criteria for fish, which were derived specifically for those media. This comparison can provide a prediction of the expected level of impact to the fish exposed to the measured environmental mercury levels.

2. Direct Assessment of Risk to NJ Fish

a. Freshwater Fish

The influence of mercury on the general and reproductive health of wild fish populations has not been well studied in general, and few NJ-specific data are available. Among the measures regularly used to assess the health or condition of fish are the ratio of the liver weight to total body weight (liversomatic index or LSI) and the ratio of gonad to total body weight (gonadsomatic index or GSI). Various researchers have conducted laboratory studies indicating that mercury can produce reproductive impairments in fish. These studies have suggested that mercury exposure can decrease gonadotropin hormone levels and impair spermatogenesis, decrease GSI, and reduce growth in juvenile fish. However, one preliminary field investigation (Friedmann et al. 1996) indicates that such adverse effects on reproductive health do not occur at levels of tissue mercury four times the United States national average.

In 1997, the NJDEP-DFGW conducted a study to determine overall status, body weight and length, serum androgen levels, GSI, LSI, kidney nuclear diameter, and serum cortisol levels in male Largemouth Bass (NJDEP 1997). The fish were collected from three bodies of water in NJ: Assunpink Lake (containing low levels of mercury), Manasquan Reservoir (containing moderate levels of mercury), and Atlantic City Reservoir (containing high levels of mercury). The mean total mercury content in fish was 0.30 ppm from Assunpink Lake, 1.23 ppm from Manasquan Reservoir and 5.42 ppm from Atlantic City Reservoir (the latter being one of the highest average values recorded for freshwater fish anywhere). Inter-lake and intra-lake analyses demonstrated statistically significant positive associations between mercury levels in fish tissue and 11-ketotestosterone in serum and a negative association between mercury and serum testosterone concentrations. These data are consistent with the hypothesis that mercury influences androgen levels in fish. Other indicators of fish 'health' such as body weight, length, condition factor, and GSI and LSI indices, as well as serum cortisol and cell nuclei diameter were similar for all three lakes. Additional research is required to help understand the implications of the hormone changes.

b. Estuarine/Marine Fish

Killifish were collected from Piles Creek, a mercury-contaminated tidal creek emptying into the Arthur Kill in an industrialized area of NJ, where sediment contained up to 200 mg/kg (average 11.2 mg/kg) of mercury (Khan and Weis 1993). These fish differed biologically from those collected in less polluted areas: Tuckerton, NJ and East Hampton, NY (Weis & Weis, 1989). Piles Creek Killifish had liver concentrations of mercury more than seven times higher, grew more slowly, reached sexual maturity earlier, and did not live as long as those from Tuckerton (Khan & Weis, 1993). Piles Creek Killifish had higher levels of mercury in brain and were slower and poorer in prey capture and predator avoidance than Tuckerton fish (Weis & Khan, 1991; Smith et al. 1995; Smith & Weis, 1997).

Killifish embryos experimentally exposed to 5 or 10 μg/L methylmercury subsequently resulted in slower prey-capture ability in Killifish larvae (Weis & Weis 1995a and 1995b). This effect was transitory and lasted about one week. However, fish exposed in the field would continue to be exposed and might not recover from such deleterious effects (Weis & Weis 1995a and 1995b).

When uncontaminated fish were exposed to conditions similar to those of the polluted creek, this led both to a reduction in their prey capture rate and an increase in brain mercury to levels similar to those of fish native to the creek (Smith & Weis 1997).

c. Summary and Conclusions

There are very few data on the direct effects of mercury on NJ fish. The results of the Weis and Weis research, reported in several papers, demonstrate significant effects on many aspects of biology, behavior and viability of Killifish. Killifish from mercury-contaminated water showed abnormal behavior and reduced viability. A study of androgen levels in largemouth bass also showed the potential for significant reproductive impairment. Much more information is needed to draw conclusions regarding the impact of mercury on fish health and reproductive capacity. Too few data are available to permit generalization of these observations to other NJ species and location, but it is reasonable to expect that analogous situations occur elsewhere and in other species. These findings raise concerns, and point out the need for research to examine the impact of mercury on the overall viability of fish in impacted NJ estuarine and marine environments.

3. Indirect Assessment of Risk to NJ Fish

a. Freshwater, Estuarine, and Marine Fish

Given the very limited direct data on the impact of mercury contamination in NJ waters on NJ fish, two indirect approaches were used to estimate risk to NJ fish species. One involved a comparison of surface water concentrations in NJ to published laboratory toxicity data on mercury and water quality criteria. The second method compares tissue concentrations of mercury in NJ fish to published data on mercury effects and Tissue Screening Concentrations (TSCs). Both methods can be characterized as a screening assessment. Additional data and a more rigorous evaluation would be needed to estimate risk to specific fish populations within the State.

With reference to the first method, numerous laboratory studies have been conducted on the toxicity of mercury in water to fish.(Table 2.22) For acute exposures (one to four days), concentrations causing mortality (i.e., LC_{50} values, which are concentrations lethal to 50% of the exposed fish) ranged from 1.24 µg/L for Threespine Stickleback (1-day exposure) to 500 µg/L for Carp (4-day exposure). Other 4-day LC_{50} values for species found in NJ include 90 µg/L for Striped Bass, 110 µg/L for Banded Killifish, 140 µg/L for American Eel, 220 µg/L for White Perch, and 300 µg/L for Pumpkinseed (US EPA 1999a). Chronic exposure to mercury causes effects at much lower concentrations than those causing acute effects due in part to bioaccumulation. Chronic exposure to MeHg reduced growth in Rainbow Trout at 0.04 µg/L (US EPA 1980). Exposure of fish eggs to mercury resulted in high embryo-larval mortality and teratogenesis at concentrations as low as 0.12 µg/L (Birge et al. 1979).

Applicable NJ water quality criteria for mercury in freshwater are 2.1 µg/L (acute; as dissolved mercury) and 0.012 µg/L (chronic; as total recoverable mercury); and for saltwater the criteria are 1.8 µg/L (acute) and 0.025 µg/L (chronic).

Table 2.23 compares chronic toxicity data and water quality criteria to mercury concentrations in NJ surface waters. In 1995-1997, 232 water samples from 78 freshwater stations were collected by NJDEP and USGS. The method detection level was 0.1 µg/L, and 94% of the samples fell below this level (i.e., not detected). A project conducted by NJDEP/DSRT measured average surface water concentrations of 0.0015 to 0.0198 µg/L in three NJ lakes (Stevenson et al. 1995). The maximum value in the DSRT study exceeded NJ's chronic water quality criteria for freshwater (0.012 µg/L). However, only approximately 6% of the 1995-1997 surface water samples exceeded 0.1 µg/L (Table 2.23) and the DSRT study maximum value of 0.0198 µg/L was less than the lowest listed chronic toxicity value (0.04µg/L).

Based on these limited data, it appears that some fish are at potential risk from the toxic effects of mercury in some of NJ's fresh waters.
Lower detection limits will help assess the risk of mercury in aquatic systems. Improvements in analytical capabilities combined with clean laboratory techniques make lower detection limits possible.

There are limited data for marine/estuarine waters. Data for the NY/NJ harbor area probably represent the high end of mercury concentrations in marine waters of NJ. Average concentrations were 0.0071 µg/L (Raritan Bay), 0.0695 µg/L (Newark Bay), 0.0862 µg/L (Hackensack River), and 0.2499 µg/L (Passaic River)(GLEC 1996).

Table 2.22. Mercury and Methylmercury Acute and Chronic Toxicity Values for Fish.

Species	Exposure Period	Water Concentration of mercury causing Acute Toxicity (LC_{50}) µg/L	Water concentration of mercury causing Chronic Toxicity µg/L	Effect/Reference
Inorganic Mercury				
Striped Bass	4-day	90	-	(US EPA 1999a)
Banded Killifish	4-day	110	-	(US EPA 1999a)
American Eel	4-day	140	-	(US EPA 1999a)
White Perch	4-day	220	-	(US EPA 1999a)
Mummichog	4-day	300	-	(US EPA 1999a)
Pumpkinseed	4-day	300	-	(US EPA 1999a)
Carp	4-day	500	-	(US EPA 1999a)
Egg Exposure	4-day post hatch	0.12-0.21		High embryo-larval mortality; teratogenesis (Birge et al. 1979)
Parental Exposure	400-day	-	0.70-0.79	High embryo-larval mortality; teratogenesis; no detectable adult pathology (Birge et al. 1979)
Methylmercury				
Threespine Stickleback	1-day	1.24	-	(US EPA 1999a)
Rainbow Trout	4-day	31	-	(US EPA 1999a)
Goldfish	1-day	80	-	(US EPA 1999a)
Mummichog	4-day	150	-	(US EPA 1999a)
Rainbow Trout	64-day	-	0.04	Growth reduction (US EPA 1980)
Brook Trout	17-day	-	0.88	Enzyme disruption (US EPA 1980)
Brook Trout	21-day	-	0.79	Organo-Hg; Growth inhibition (US EPA 1980)
Medaka	3-months	-	1.8	Impaired spermatogenesis (Wester 1991)

A comparison of these data to the marine/estuarine surface water chronic criteria of 0.025 µg/L indicates that waters in the more urban areas of the harbor exceeded water quality criteria. This indicates that fish in these waters are at potential risk from the toxic effects of mercury contamination.

Table 2.23. Comparison of NJ Surface Water Criteria with Average Surface Water Concentrations of Mercury.

NJ Surface Water Criteria	Location	Average Surface Water Concentrations	Date
		Freshwater	
Acute 2.1 μg/L	78 Water-Quality Stations	0.053 μg/L* (94% of samples below detection limit of 0.1 μg/L)	1995-1997
Chronic 0.012 μg/L	41 Water-Quality Stations	<0.1 μg/L (all samples below detection limit of 0.1μg/L)	1998
	Three NJ Lakes	0.007 μg/L (0.0015 to 0.0198 μg/L*)	1992
		Marine/Estuarine	
Acute 1.8 μg/L	Raritan Bay	0.0071 μg/L	1995
Chronic 0.025 μg/L	Newark Bay	0.0695 μg/L*	1995
	Hackensack River	0.0862 μg/L*	1995
	Passaic River	0.2499 μg/L*	1995

** Concentration exceeds the chronic criteria for freshwater or salt water*

The second method for estimating risk to NJ fish species compares tissue concentrations of mercury in NJ fish to published data on mercury effects and Tissue Screening Concentrations (TSCs). However, there is limited information on the relationship between fish tissue concentration and adverse effects. Table 2.24 lists tissue and effects data from several sources for fish in general, and for specific species (e.g., Rainbow Trout). Based on these data, adverse effects are evident at whole body concentrations as low as 1.3 ppm (growth) and at muscle concentrations of 0.232 ppm (behavior). Shephard (1998) recommended the use of tissue screening concentrations (TSCs) to assist in determining the risk of bioaccumulated contaminants. TSCs were defined as "whole body, wet weight tissue residues of chemicals, which if not exceeded, pose little chance of causing adverse toxicological or ecological harm to aquatic biota." These values were derived by applying bioconcentration factors to the ambient water quality criteria. The TSC for mercury is 0.06 μg/g for freshwater (Shephard, 1998). The hazard quotient (HQ) method was used to conduct a screening level risk assessment where:

$$HQ = \frac{\text{Estimated Environmental Concentration}}{\text{Benchmark Concentration}}$$

HQs (see Table 2.25) were generated by comparing NJ fish tissue concentrations of mercury separately to the mercury TSC value and to the lowest observed effect concentration from Table 2.22 (i.e., 0.232 μg/g for adult fish). Exposure was estimated by using the data from the fish collected at 55 locations in NJ (ANSP 1994).

As indicated by the range in HQs, at least some of the fish samples for all of the species exceeded the TSC or effects thresholds (i.e., HQ>1). This indicates that at least some species of fish in some NJ waters are at risk for the effects of mercury. Largemouth Bass and Chain Pickerel are probably at increased risk based on the large HQs for those species.

Table 2.24. Adverse Effects at Observed Fish Tissue Concentrations.

Species	Mercury Concentration (µg/g; wet weight)	Effects	Reference
Brook Trout	5-7 (whole body)	Mortality, decreased growth, sluggishness, deformities	McKim et al. 1976
Rainbow Trout	20-30 (whole body)	Reduced appetite; gill hyperplasia	Niimi and Lowe-Jinde 1984
	4-27 (whole body) 9-52 (muscle)	Appetite & activity loss followed by death	Niimi & Kissoon 1994
	12-23 (muscle)	Reduced growth	Wobeser 1975
Northern Pike	7-9 (muscle)	Emaciation	Lockhart et al. 1972
Walleye	1.7-3.1 (whole body)	Decreased weight, length, & gonadosomatic index	Friedmann et al. 1996
Fathead Minnow	1.3 (whole body)	Decreased weight & length	Snarski & Olson 1982
	4.5 (whole body)	No spawning	
Fish	0.232 (muscle)	Decreased swimming ability	Rompala et al. 1984
Fish	10-30 (whole body)	Toxicity	Spry and Wiener 1991
Juvenile or Adult Fish	9-20 (whole body)	Harmful effects	Wiener 1996
Fish Eggs or Embryo	0.07-0.10	Adverse effects	Wiener 1996

Table 2.25. Hazard Quotients (HQs) Calculated from the Tissue Concentrations (Range of Concentrations) by Species Divided by the Tissue Screening Concentrations (TSC) and Effect Concentration.

NJ Fish Species (no. of samples)	Hazard Quotient	
	Based on TSC	Based on Effects Concentration
Largemouth bass (146)	0.8-149	0.2-38
Chain pickerel (62)	1.5-47	0.4-12
Smallmouth bass (21)	1.3-8.5	0.3-2.2
Channel catfish (12)	1.2-12	0.3-3.1
Brown bullhead (15)	0.3-7.8	0.1-2.0

b. Summary and Conclusions

The limited data, which allow comparison of mercury concentration in NJ fish to published criteria and guidelines, indicate the potential for chronic effects to fish in some waters of the State due to mercury. This potential is reflected in the exceedence of water quality criteria for chronic effects for both freshwater and saltwater fish. In particular, the NY-NJ Harbor area has exhibited mercury water concentrations above water quality criteria. Monitoring using more sensitive (i.e., lower detection limit) methods is needed to assess the levels of mercury in surface waters. It is apparent from both direct and indirect methods that some fish in some NJ waters may be at risk of mercury toxicity.

E. Mercury in NJ Birds

1. Assessment of NJ Species Potentially at Risk

The trophic level and feeding habitats of a bird species will influence its exposure to mercury. Piscivorous bird species are at greatest risk to the effects of mercury due to the biomagnification of mercury through the aquatic food chain. State threatened and endangered species, such as the piscivorous Osprey, Bald Eagle, Black Skimmer, and Least Tern may be at increased risk due to their trophic level and the potential cumulative effects of other contaminants in addition to mercury on reproduction (e.g., DDT/DDE, PCBs). The Peregrine Falcon, another NJ endangered species, may also be at high risk since its diet includes piscivorous birds (such as terns). A variety of large birds including herons and egrets, gulls, terns, and skimmers which typify the NJ shore, may also be at increased risk due to greater mercury exposure from the fish they eat.

Smaller birds that feed at lower trophic levels in the aquatic food chain also may be exposed to increased amounts of mercury due to their high food consumption rate relative to larger birds (US EPA 1997f).

2. Wildlife Criterion Value (Surface Water Concentration)

US EPA (1997d) calculated a wildlife criterion value of 50 pg/L of MeHg in surface water for protection of piscivorous wildlife. Based on this value, they calculated the concentration in fish that would meet this criterion. For trophic level 3 fish (e.g., sunfish) this value is 0.077 μg/g , and for trophic level 4 fish (e.g., Largemouth Bass) this value is 0.346 μg/g. Therefore, concentrations of MeHg in fish would need to be at or below these values to be protective of piscivorous birds and mammals. For example, the MeHg concentration in piscivorous fish species (e.g., Pickerel, Largemouth Bass) would need to be less than or equal to 0.346 μg/g to protect species that feed on them. The MeHg concentration in omnivorous fish (e.g., sunfish) prey would need to be less than or equal to 0.077 μg/g to protect wildlife species including larger predatory fish.

Based on these values, a comparison for the 55 NJ waterbodies sampled in 1992-93, indicates that top trophic level fish exceed the criterion value of 0.346 μg/g for protection of piscivorous wildlife and also exceed the new EPA surface water criterion of 0.3 μg/g (in fish tissue). The data indicate that Largemouth Bass in 70% (23 of 33) and Chain Pickerel in 82% (18 of 22) of the waterbodies exceeded this concentration. Overall, 60% of the Largemouth Bass samples and 74% of the Chain Pickerel samples exceeded this value. This indicates that certain piscivorous wildlife species feeding on these species in these waters are at potential risk from the effects of mercury. Additional data collection and a more comprehensive analysis are recommended for trophic level 3 and 4 fish.

The EPA provided relative ranking of exposure for the species considered: Kingfisher > River Otter > Loon = Osprey = Mink = Bald Eagle. The Belted Kingfisher has a higher daily mercury intake than Osprey, and EPA estimates that 29% of its national range has high atmospheric mercury deposition (5 $\mu g/m^2$). For Osprey and Bald Eagle, 20% and 34% of their national range respectively receives high mercury deposition. Both species were severely impacted by chlorinated hydrocarbon pesticides in the 1950's and 1960's and have recovered through a combination of pesticide bans and aggressive management. Whether mercury currently impairs their survival or reproduction requires additional monitoring.

3. *Criteria for Mercury in Birds*

US EPA (1997d) concluded, based on a review of laboratory and field data, that adverse impacts on avian populations are possible at mercury concentrations exceeding the following values (fresh weight): feathers - 20 μg/g (Scheuhammer 1991); eggs - 2.0 μg/g (after conversion from dry weight) (Scheuhammer 1991), and liver - 5 μg/g (Zillioux et al. 1993). EPA indicated that these numbers should be used with caution, because the literature contains reported thresholds that are higher than and lower than these values. Some of the NJ data approach these thresholds. Evidence of lower thresholds (e.g., developmental abnormalities in Common Tern chicks [Gochfeld, 1980]) indicate that NJ species may be at potential risk.

Summarizing literature on reproductive and behavioral outcomes, Burger and Gochfeld (1997) identified a level of 0.5 ppm (wet weight) in eggs and 5.0 ppm in feathers as criteria above which adverse effects could be anticipated. Feather levels in the 40-60 ppm range were associated with sterility and total chick mortality, while levels in the 5-40 ppm range were associated with reduced hatchability and behavioral abnormalities (Burger and Gochfeld 1997; Eisler 1987).

4. *Mercury Levels in Birds of NJ and the New York Harbor and Bight*

Birds have been monitored for mercury since the 1960's and data from NJ, and the New York Bight comprise a significant portion of the contaminants' data compiled in the national database by the US Fish and Wildlife Service (B. Rattner, Personal Comm).

a. *Common Loon*

The Common Loon (*Gavia immer*), icon of the northwoods, is a species at risk, declining over much of its breeding range. This piscivorous waterfowl breeds on fresh water of Canada and the northern United States. It visits NJ only on migration and as a winter resident between September and April on both fresh and saltwater. Its population has declined, due primarily to acid deposition, but loons have high mercury levels, and Barr (1986) found adverse reproductive effects in loons exposed to 0.3 μg/g of mercury in trophic level 3 fish.

b. *Colonial Waterbirds*

Species such as gulls and terns, herons and egrets nest in large groups, referred to as "colonies"on islands or other protected habitats mainly along the coast. Chicks are fed by the parents, who fish in the waters within a few kilometers of the colonies. The adults thus "collect" fish from a relatively small area over a period of weeks, thereby integrating exposure over time and space. Several studies of mercury in such species have been conducted in estuarine systems of the New York Bight from Fire Island, NY to Barnegat Bay, NJ.

In a summary of studies of mercury in eggs of nine coastal waterbird species from the New York Bight, Burger and Gochfeld (1997) found that mean mercury levels exceeded 0.5 ppm for Snowy Egrets from Lavalette, NJ; Black Skimmers and Common Terns from NY and NJ; and Forster's Tern and Herring Gulls from Barnegat Bay. Forster's Terns had the highest values. Only Laughing Gulls from Barnegat Bay had a mean less than 0.5 ppm. The same study of feather mercury, however, revealed that most of these colonial species had mean mercury below 5 ppm. Only Snowy Egrets from the Barnegat Light colony and Great Egrets from Lavallette, exceeded an average of 5 ppm. The Great Egret eats relatively large fish, and Jurczck (1993) concluded that in south Florida this species was exposed to excessive amounts of mercury, thus placing the population at risk. Currently this species has an apparently stable population in NJ that breeds and partly winters in the state.

The insectivorous Cattle Egret also had moderately high levels of mercury, even though it is lower on the food chain. Mercury levels in its feathers averaged 0.60 ppm in the Arthur Kill colonies and 1.6 ppm in the Pea Patch, Salem County colony. These are substantially lower than the 3.5 ppm average at Aswan, Egypt (Burger et al. 1992), but are nonetheless elevated.

In NJ, Herring Gull eggs contained 0.26 μg/g (geometric mean wet weight) of mercury at Shooter's Island, 0.47μg/g at Lavallette, and 0.33 μg/g at Log Creek (Gochfeld 1997). Surprisingly, mercury levels in these two Barnegat Bay colonies were significantly higher than in eggs from the Arthur Kill (geometric mean=0.26 μg/g) and Jamaica Bay (geometric mean=0.29 μg/g) (Gochfeld 1997). The Barnegat Bay levels were comparable to the median for German colonies (about 0.40 μg/g; Lewis et al. 1993) and close to those for highly contaminated Great Lakes colonies (mean=0.51μg/g; Gilman et al. 1977). The source of this elevated mercury has not been identified.

Clearly, with these mean values, some of the birds at the high end would have been at risk of adverse effects. Burger (1997b) compared Herring Gull feather mercury levels in four Long Island, three NJ and one Virginia colony. The highest values (geometric means) were 2.66 μg/g in western Long Island Sound, and 2.45 μg/g in Barnegat Bay. These compare with median values from central Europe of about 5.0 μg/g (Lewis et al. 1993).

Laughing Gulls, mostly from breeding colonies in NJ, were killed at J.F. Kennedy Airport as part of a federal control program to avert aircraft collisions. The carcasses were collected and the tissue analyzed for mecury. Mercury levels averaged 0.55 μg/g in liver, 0.48 μg/g in kidney and 3.5 μg/g in feathers (Gochfeld et al. 1996).

The Roseate Tern (*Sterna dougallii*) is a federal endangered species, which formerly nested at least rarely in NJ. Samples from a Long Island colony revealed a slight decline in mercury in eggs (geometric mean, wet weight) from 1.49 μg/g (1989) to about 1.07 μg/g (1994). Between 1971 and 1982 the geometric mean mercury level in Common Tern eggs (Long Island, NY) declined from 0.61 to 0.25 μg/g (Burger and Gochfeld 1988). Herring Gull feathers from Captree, NY revealed no temporal trend between 1990 and 1993 (values of 0.2 μg/g to 0.4 μg/g in adults) (Burger 1995).

As evidence of biomagnification in Raritan Bay, mercury levels were higher in fish eating Common Terns than in omnivorous Herring Gulls and Greater Scaup or herbivorous Black Ducks (Burger et al. 1984). Some of the highest mercury levels in feathers were found in Black Skimmers from the New York Bight, with up to of 13.0 μg/g (Burger and Gochfeld 1992).

c. Waterfowl

Ducks and geese are prominent features of NJ wetlands, particularly in winter, and ducks have been used as indicators of contaminant levels. Greater Scaup, once the most abundant duck wintering in Raritan Bay, were monitored in 1980-81 (Burger et al. 1984) and again in 1996-97 (Cohen et al. 1999). The mean levels in liver were essentially unchanged (0.73 vs. 0.86 μg/g). Moreover, Cohen et al. (1999) found that mercury levels were higher in Scaup from Sandy Hook than from eastern Long Island or Long Island Sound, suggesting a local source of contamination rather than contamination on the breeding grounds in Canada.

Moreover, mercury levels increased from early winter (when the birds arrived from their Canadian breeding grounds) to early spring (before they departed northward), again indicative of local exposure to mercury in Raritan Bay.

Three species of ducks from Raritan Bay (1980-1981) were analyzed for mercury in liver. Mean levels were 0.53 μg/g (wet weight) in Black Duck, 0.73 μg/g in Scaup, and 0.32 μg/g in Mallards (Burger and Gochfeld 1985; Gochfeld and Burger 1987b). In 1983, Black Ducks, Greater Scaup and Herring Gulls all averaged less than 0.5μg/g of mercury in liver (wet weight) while Common Terns exhibited levels were at 0.7 μg/g.

d. Shorebirds

Many migratory shorebird species feed mainly on Horseshoe Crab eggs and small invertebrates. Average total mercury in Horseshoe Crab eggs from Delaware Bay were 27 ppb (1993), 93 ppb (1994), and 12 ppb (1995) (Burger 1997). Mercury levels were measured in feathers of three shorebird species from Delaware Bay in the early 1990s. Red Knot averaged 1.15 ppm, Sanderling 2.8 ppm, and Semi-palmated Sandpiper 0.021 ppm. These highly migratory species may be exposed in their tropical wintering grounds or their Arctic breeding grounds, as well as along Delaware Bay (Burger 1993).

e. Raptors

The falcons, hawks and eagles (collectively called raptors) are familiar birds to the public. The Osprey is a characteristic feature of the Jersey Shore; the falcon the emblem of the US Airforce, and the Bald Eagle is our national symbol. NJ has invested extensively in protecting raptorial birds. The populations of most species in the eastern United States have recovered. However, the populations of Ospreys, Peregrine Falcons and Bald Eagles has declined precipitously due to the bioaccumulation of chlorinated hydrocarbon pesticides, and the population of Northern Harrier (Marsh Hawk), has declined probably because of habitat loss. NJ has had an aggressive program to restore Eagles and Ospreys and to protect Northern Harrier habitat, as well as the crucial habitat in Cape May County required by migratory hawks. For migratory species such as the Peregrine, chlorinated hydrocarbon exposure in South America continues to be a threat.

Whether mercury has contributed to past declines or may impair future population, is not known. There are few data on mercury levels in NJ raptors (Bald Eagle, Osprey, Peregrine Falcon) but this sparse data show that raptors can accumulate high concentrations of mercury. Comparable data obtained systematically from NJ breeding populations would provide valuable information for a management program. As indicated earlier, piscivorous raptors, such as the Osprey and Bald Eagle, are at greater risk due to increased mercury exposure from their diet.

As of the mid-1990's, the population of Bald Eagles in the Delaware River basin had rebounded from one pair in the early 1970's to 13 pair. Blood mercury levels in 35 Bald Eagle chicks (1993-1996) showed a geometric mean of 140.6 μg/L and were generally below 300 μg/L. The five highest mercury concentrations between 756 and 1549 μg/L were found in 5 of 6 Union Lake nestlings (Clark 1999). These levels are quite high. Additional levels for mercury in NJ raptors are shown in Table 2.7 (Volume II, Chapter 6).

Osprey (*Pandion haliaetus)* and other avian populations have progressively recovered from the adverse effects of widespread pesticide usage. Recovery of several localized populations of Ospreys and Bald Eagles nesting along the Delaware Bay continue to be hampered by organochlorine pesticides. Results from surveys in 1977 and 1987 contained some of the highest contaminant residues recorded in Bald Eagle eggs from the Delaware Bay region (Steidl et al. 1991).

5. Mercury and Developmental Defects

In the late 1960's and early 1970's, an epidemic of developmental defects was detected in several species of colonial birds in the New York Bight. These included craniofacial abnormalities (anencephaly, cyclopia, micrognathia, crossbill), limb abnormalities (phocomelia, excess limbs and toes), and feather defects. In the 1980's similar defects occurred in birds in the Great Lakes. Total mercury levels in chicks of Common Terns from western Long Island ranged from 165-750 µg/L in blood and 0.8 to 2.6 ppm in feathers, with abnormal chicks having higher levels than normal ones ($p < 0.05$). Developmental abnormalities in Common Tern chicks were associated with significantly higher mercury levels in liver of 2.2 vs. 1.1 µg/g and brain levels of 0.85 vs. 0.42 µg/g (Gochfeld 1980).

Common Terns with developmental defects associated with high levels of mercury also had elevated PCB concentrations (Hays & Riseborough 1971), and an additive or synergistic affect between these pollutants was proposed (Gochfeld 1975).

6. Summary and Conclusions: Mercury in NJ Birds

Mercury levels in tissues, feathers, and eggs of several populations of NJ and New York Bight birds are close to or above levels anticipated to impair behavior, reproduction, growth and survival. Mercury was associated with developmental defects in Common Terns in the 1970's and high mercury levels are considered one of the stressors causing the decline of Common Loons. Mercury in the fish diet of Bald Eagles and Osprey, appears to be elevated in the Delaware Bay region and may be a contributing factor to their relative lack of recovery in these regions.

F. Mercury in Other NJ Biota

Data on mercury levels in animals other than birds and fish are sparse in both the number of observations and the extent of taxonomic coverage.

1. Marine Invertebrates

Blue Mussels (Mytilus edulis) are widely used as an indicator of marine pollution. Mussels have been sampled by NOAA in the Hudson-Raritan estuary from 1986 to 1997 (NOAA 1998). Mercury levels ranged from 0.18 to 0.72 µg/g (dry weight), with the highest values in the Upper Bay and the lowest values in the Hudson River (below Peekskill). The highest value along the NJ portion of the estuary was 0.36 µg/g observed in the Shark River in 1991.

Horseshoe Crab (Limulus polyphemus): Delaware Bay has been the center of abundance of Atlantic Coast Horseshoe Crab, but this population has been jeopardized by over-harvesting, primarily for the conch and eel bait trade. Horseshoe Crab eggs are essential food for migrating shorebirds. Burger (1997) reported that Horseshoe Crab eggs collected in Delaware Bay in 1993, 1994, and 1995 averaged 0.027-0.093 µg/g, while adult Horsehoe Crab muscle averaged 0.053 µg/g (mean, wet weight). At these levels, it seems likely that mercury is not affecting this species.

2. *Mammals*

Mammals are relatively infrequently sampled for pollutants. Muskrats *(Ondatra zibethicus)* were collected from the Meadowlands and a reference area in NJ in 1975 (Galluzzi 1976). Thirty-six samples of eight species of mammals were collected in the Hackensack Meadowlands in 1978 (Galluzzi 1981). Average mercury concentrations for these mammals are listed in Table 2.26. Mercury concentrations in the Hackensack Meadowlands' Muskrats were generally higher than the Muskrats from the reference location in Morris County. Muskrat muscle, liver, and kidney mercury concentrations were generally higher in the Berry's Creek area as compared to the other two locations in the Meadowlands. The highest mercury concentrations were observed in Opossum *(Didelphis marsupialis)* tissues. The Opossum is an omnivore while several of the other mammal species are generally herbivores (e.g., Muskrat, Vole, and Rabbit). The Opossum's more diverse feeding habits may explain the higher mercury levels (i.e., greater exposure to mercury through food items).

3. *Reptiles*

Table 2.27 lists a few reptile species that were also collected in the Hackensack Meadowlands in 1978 (Galluzzi 1981). Mercury levels in the Diamondback Terrapin *(Malaclemys terrapin)* muscle and liver tissue were elevated compared to the other reptiles and mammals. This may be due to the Terrapin's diet of aquatic animals, leading to greater mercury exposure. The Garter Snake (*Thamnophis sirtalis*), which feeds on fish, amphibians and invertebrates had mercury levels one order of magnitude higher than the Milk Snake (*Lampropeltis doliata*), which feeds mainly on baby birds and mammals (Smith & Brodie, 1982). However, the sample sizes for all three species are very small and more data are needed before generalizations can be drawn.

The Pine Snake *(Pituophis melanoleucus)* is a threatened species that occupies the increasingly fragmented habitat of the Pine Barrens of southern NJ. Total mercury in body tissue (mainly muscle, bone, and connective tissue) of hatchlings ranged from 0.27 ppm in 1985 to 0.05 ppm in 1990. (Burger 1992)

Table 2.26. Concentrations of Mercury in Mammal Tissue in NJ.

Location	**Average mercury Concentration (µg/g; wet weight)**	**Source**
	Muskrat *(Ondatra zibethicus)*	
Berry's Creek (West Riser ditch) (n=10)	Muscle=0.024 Liver=0.016 Kidney=0.279	Galluzzi 1976
Berry's Creek (n=10)	Muscle=0.027 Liver=0.036 Kidney=0.176	Galluzzi 1976
Anderson Creek (Secaucus) (n=10)	Muscle=0.006 Liver=0.020 Kidney=0.068	Galluzzi 1976
Sawmill Creek (n=10)	Muscle=0.006 Liver=0.012 Kidney=0.111	Galluzzi 1976
Montville (Morris County) (n=10)	Muscle=0.003 Liver=0.0005 Kidney=0.003	Galluzzi 1976

Hackensack Meadowlands (n=5)	Muscle=0.01 Liver=0.050 Kidney=0.030	Galluzzi 1981
Opossum *(Didelphis marsupialis)*		
Hackensack Meadowlands (n=3)	Muscle=0.17 Liver=1.25 Kidney=1.80	Galluzzi 1981
Norway Rat *(Rattus norvegicus)*		
Hackensack Meadowlands (n=4)	Muscle=0.05 Liver=0.11 Kidney=1.22	Galluzzi 1981
Cottontail Rabbit *(Sylvilagus sp)*		
Hackensack Meadowlands (n=3)	Muscle=ND Liver=0.15 Kidney=0.51	Galluzzi 1981
House Mouse *(Mus musculus)*		
Hackensack Meadowlands (n=11)	Muscle=0.01 Liver=0.06 Kidney=0.34	Galluzzi 1981
Vole *(Microtus sp)*		
Hackensack Meadowlands (n=7)	Muscle=ND Liver=ND Kidney=0.16	Galluzzi 1981
Raccoon *(Procyon lotor)*		
Oakland (Bergen County) (n=1)	Muscle=0.064 Liver=0.248 Kidney=0.227	Galluzzi 1981

4. Vegetation

Measuring mercury levels in terrestrial vegetation and biota may help determine major areas of deposition in the state and may serve as living indicators of mercury contamination through atmospheric deposition. However, there are currently few data on mercury in plants in NJ and no information on adverse impacts. Mercury levels in rye grass and sphagnum moss were measured near the Warren County Resource Recovery Facility (Carpi et. al. 1994). Total mercury in moss exposed at sites within 1.7 kilometers of the incinerator had significantly higher mercury levels (average 206 ng/g, or ppb) compared to samples exposed at greater distances from the facility (average 126 ng/g).

Mercury levels in aquatic vegetation have been measured in NJ. Pond lilies in Mountain Lake, Lake Assunpink, and Parvin Lake were reported to be 7 to 13 ng/g (Stevenson et al. 1995). More information on mercury levels in aquatic vegetation and non-fish biota are needed in order to characterize the extent of mercury pollution and provide baselines for detecting temporal trends.

Table 2.27. Concentrations of Mercury in Reptile Tissue in the Hackensack Meadowlands (Source: Galluzzi, 1981).

Species	Tissue	Average Mercury Concentration (μg/g; wet wt.)
Diamondback Terrapin *(Malaclemys terrapin)* (n=2)	Muscle	Muscle=0.76 Liver=5.6 Kidney=1.8
Garter Snake *(Thamnophis sirtalis)* (n=3)	Muscle	Muscle=0.28 Liver=1.40 Kidney=0.32
Milk Snake *(Lampropeltis doliata)* (n=1)	Muscle	Muscle=0.012 Liver=0.044 Kidney=0.027

5. Summary and Conclusions: Mercury in Other NJ Biota

Very limited data on mercury exposure in NJ plants and animals other than birds and fish are available. The data suggests that omniorous mammalian species have higher mercury levels than hebivorous species. Data on carnivorous species are lacking. For reptiles, elevated levels are associated with the consumption of aquatic biota (fish and invertebrates). Information for evaluating the ecological risk implications of these isolated observations is lacking, and more information on mercury in these animals and in various plant species is needed.

G. Recommendations

To understand the impacts of mercury on biota and ecosystems, it is necessary to systematically collect data on a group of representative species (bioindicators) from a wide variety of ecosystems, stratified by presumed exposure to mercury. A systematic assessment of mercury should be carried out in conjunction with other bioaccumulative pollutants and other heavy metals in NJ plants and animals.

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, NJ should:

- **Consider establishing the mercury-contaminated sites in the Berry's Creek area as an Environmental Research Park, patterned on the National Environmental Research Park system. This could serve as a resource for studies and monitoring of the complex processes governing the fate and transport of mercury in both the terrestrial and estuarine environment.**

(From Recommendation "M.5." in Volume 1).

The massive contamination of the Ventron/Velsicol and Berry's Creek area, provides a unique opportunity to understand the processes controlling the sequestration, availability, and ecological effects of mercury. Since some local residents consume wildlife from this ecosystem, human exposure can also be clarified. The opportunity exists to declare Berry's Creek Environmental Research Park, patterned on the National Environmental Research Park system (DOE 1994), and to fund research studies and monitoring to clarify the complex processes governing the fate and transport of mercury in both the terrestrial and estuarine environment.

Expand and institutionalize routine monitoring for mercury in fish from NJ waters through State-level programs (From Recommendation "G" in Volume 1).

Regular monitoring of freshwater fish, including selected species of recreational and ecological importance, should be conducted to identify temporal and spatial trends in mercury and other bioaccumulative contaminants, to allow the state to keep potential consumers informed of levels, to provide information for updating advisories, and to identify new or unsuspected sources of contaminants.

The scope of sampling should be expanded to additional water bodies to support fish advisories.

There should be regular and systematic monitoring of saltwater species in NJ waters for mercury and other contaminants, in order to provide appropriate consumption advisories. The recent (January 2001) fish consumption advisories issued by FDA and EPA are not NJ-specific.

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, NJ should:

- **Encourage federal agencies to expand existing national research on the ecological effects of mercury, particularly on piscivorous (fish-eating) fish, birds and mammals (particularly marine mammals).**

(From Recommendation "M.3." in Volume 1).

Reduce mercury levels in fish and other biota. Mercury concentrations in freshwater and estuarine fish in New Jersey should, at a minimum, be in compliance with the EPA's recent Surface Water Criterion of 0.3 μg/g methylmercury in tissue. This guidance value, aimed at protecting human health, may not be adequate to protect the health of the fish. Therefore mercury levels in surface water and fish tissue should achieve levels protective of aquatic life and of wildlife (the criterion for which is currently under development). Assessing this criterion requires the use of improved analytic methodologies that lower detection levels by at least an order of magnitude. (From Recommendation "Q" in Volume 1).

Additional research in the domain of aquatic toxicology is needed to understand how mercury effects fish health in terms, not only of survival, but behavior, condition, and reproduction, all of, which are inter-related. The dose-response relationship between mercury exposure measures (mercury in sediment, prey species, or tissue) and fish health need to be established.

Additional data collection and a more comprehensive analysis of fish tissue concentrations and their comparison to effect levels should be carried out especially for tropic levels 3 and 4 fish in NJ, as it appears that these fish are most at risk for adverse effects and are consumed by piscivorous species. Monitoring using more sensitive methods (i.e., lower detection limit) is needed to assess the levels of mercury in surface waters to more precisely estimate the potential for adverse effects on fish on a waterbody-by-waterbody basis.

Develop improved environmental indicators of the impact of mercury on NJ's environment. To accomplish this, NJ should:

- **Develop and apply indicators of trends of mercury in environmental media, including air deposition, mercury concentrations in surface water, mercury**

entry into aquatic food chains, mercury levels in fish tissue, mercury levels in human tissue in the NJ population, and mercury levels in feathers of piscivorous birds nesting in NJ.

(From Recommendation "O.2." in Volume 1).

Establish a monitoring program for mercury and other contaminants in NJ birds, including but not limited to, threatened and endangered species.

Chapter 9 - IMPACT OF MERCURY ON PUBLIC HEALTH IN NJ

A. Introduction

In recent years, mercury has received increasing attention because of its known or suspected impacts on human health. Historically, this concern has resulted from occupational exposures (e.g., "Mad Hatter's" disease), and from large-scale poisonings (Minamata and Iraq). Currently, however, concern is also focused on more subtle health effects. While use of thimerosal (an organic mercury compound) in vaccines is currently an issue of some concern in the medical community, it was beyond the scope of this Task Force. We will focus here largely on methylmercury in fish, inorganic mercury salts in drinking water, and on releases of elemental mercury through spills and intentional releases, representing largest current *environmental* impact in NJ.

B. Methylmercury Exposure from Fish Consumption in NJ

Methylmercury (MeHg) is the most toxic of the mercury compounds and is the one to which the greatest number of people is exposed. Ingestion of fish is the only significant route of exposure for the general population to MeHg. It is widely accepted that the most sensitive target is the developing nervous system and, therefore, the fetus and infant are the most susceptible populations. To protect these, it is necessary to understand and limit exposures to MeHg during pregnancy and in women who may soon become pregnant.

Data on the impact of mercury in NJ due to fish consumption is available from two sources: 1) a study of mercury level in blood and hair in a sample of the NJ pregnant population (Stern et al., 2001); and 2) a diet recall study of fish consumption in the NJ population which used the recall data to also indirectly predict levels of mercury exposure (Stern et al. 1996; NJDEP, 1995). Additional studies of fish consumption patterns in NJ have been published by Pflugh et al. (1999), Burger et al. (1999) and May and Burger (1996).

1. Mercury Exposure in Pregnant Women - NJDEP-DSRT/EOHSI study

Data on exposure to mercury in the NJ pregnant populations is available from a recent study (Stern et al 2001). This study sampled 189 women during their regular visits to six obstetric practices and clinics in northern and central NJ between 1995 and 1997. These locations reflected both coastal and inland areas of the state. Blood and hair were analyzed for total mercury. A subset of the hair samples was also analyzed for MeHg. For those individuals who consume even a moderate amount of fish, methylmercury accounts for the most of the total mercury burden (US EPA, 1997b). Hair strands preserve a record of exposure to mercury during the entire time of their growth, while blood reflects relatively recent exposures. In addition, demographic and diet information was obtained. The study was designed to encounter women early in their pregnancy, and 70% of the women sampled in the study were in their first trimester of pregnancy. The distributions of total mercury in hair and blood from the study sample are given in Tables 2.28 and 2.29 respectively. The data are shown graphically in Figure 2.7. Because the sample size in this study was relatively small, the distributions of age, race, and education of the women in the study were compared to the distributions in the 1995 Residential Birth Data File maintained by the NJ Department of Health and Senior Services and adjusted (weighted) to reflect the distributions among women giving birth statewide. The following tables present the unweighted mercury concentration data as well as the weighted data. The similarity of results indicates that the sample was adequately representative.

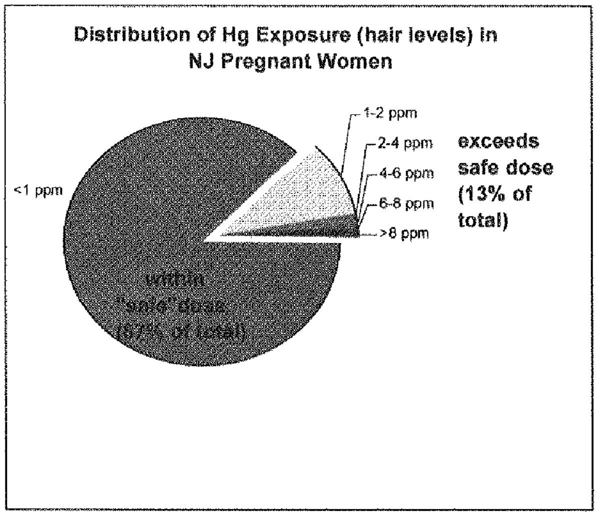
Table 2.28. Distribution of Total Mercury in Hair from the Sample of NJ Pregnant Women.

Mercury concentration (µg/g – ppm)	Number (total = 189)	Unweighted percent of total	Age weighted percent of total	Race weighted percent of total	Education weighted percent of total
≥0.1 - <1.0	165	87.3	84.5	86.9	89.2
1.0 - <2.0	18	9.5	12.3	9.9	8.1
2.0 - <4.0	3	1.6	2.0	1.5	1.7
4.0 - <6.0	1	0.5	1.0	0.6	0.3
6.0 - <8.0	1	0.5	0.1	0.6	0.3
8.0 - ≤10.0	1	0.5	0.1	0.5	0.0

Table 2.29. Distribution of Total Mercury in Blood from the Sample of NJ Pregnant Women.

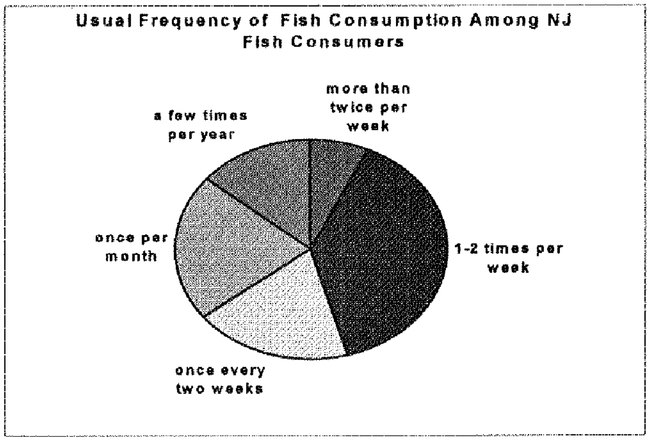
Mercury Concentration (µg/l – ppb)	Number (total = 149)	Unweighted percent of total	Age weighted percent of total	Race weighted percent of total	Education weighted percent of total
>0.25 - <1.0	127	85.2	76.9	84.4	83.6
1.0 - < 5.0	15	10.1	14.8	10.9	10.1
5.0 - <10	5	3.4	5.6	3.2	5.0
≥10	2	1.3	2.6	1.6	1.3

Figure 2.7. Distribution of Total Hg in Hair from the Sample of NJ Pregnant Women.



(Note: 1 ppm mercury in hair approximately corresponds to the U.S.EPA Reference Dose for MeHg. This is the level of exposure at which no significant adverse effect is expected over a lifetime of exposure even to the most sensitive groups in the population

Figure 2.8. Reported Usual Consumption of Fish Among 1,000 New Jersey Survey Respondents Who Reported at Least Some Fish Consumption in 1995.



Assuming the commonly used convention that samples below the detection limit had a mercury concentration of one-half the detection limit, the mean blood mercury concentration was 0.99 μg Hg/L blood (S.E. = 0.28 μg /L). The great majority of the participants had blood mercury concentrations less than 1.0 μg/L. However, approximately 5% had concentrations between 5.0 and 10 μg /l, and two had concentrations greater than 10 μg /L. Likewise, assuming samples below the detection limit had mercury concentration of one-half the detection limit, the mean hair mercury concentration was 0.53 μg Hg/g hair (S.E. 0.07 μg/g). The great majority of the sample had hair mercury concentrations less than 1.0 μg/g. However, 3% had concentrations greater than 2.0 μg/g and 2% had concentrations greater than 4.0 μg/g.

Total mercury concentration in hair was significantly correlated with the calculated intake of mercury based on the subject's reported fish consumption. The correlation was, however, weaker than might be expected. This probably reflects the fact that most of the participants ate fish infrequently. Two of the participants whose hair mercury concentrations were among the highest had low blood mercury concentrations and reported a low level of fish consumption. These cases may reflect significant inorganic mercury exposure.

Demographic factors were investigated in a regression analysis in an attempt to identify factors that may be predictive of MeHg exposure. Among the factors that *were not* significantly predictive of exposure were whether someone in the subject's family fished in either saltwater or freshwater at least once per year, the number of self-reported dental fillings, and self-identification as either Asian or Hispanic (compared to self-identification as White). Blacks had lower mercury levels than Whites. People with some college education had lower levels of mercury than those who did not complete high school.

The recent data on mercury levels in hair and blood in women of childbearing age nationwide generated as part of the National Health and Nutrition Examination Survey (NHANES IV) (MMWR, 2001) are in good agreement with these estimates, indicating that greater than 10% of women of childbearing age had hair concentrations of methylmercury greater than 1 μg/g. There are few other measurements of mercury exposure in US populations. In a 1981 nationwide sample of women of childbearing age (15-45 years old) all of who consumed fish (Smith et al., 1997), approximately 20% had hair mercury levels greater than 1 μg/g and approximately 5% had levels greater than 2 μg/g. These results agree closely with those from the NJ pregnant population.

Mercury speciation was carried out in 17 hair samples and MeHg accounted for 67% of the total mercury in these samples. Thus, 33% of the total mercury in hair was inorganic mercury. Some of this inorganic mercury represents direct exposure to inorganic mercury, but since MeHg is slowly metabolized to inorganic mercury in the body, this value probably overestimates direct inorganic mercury exposure. At very low total mercury concentrations, inorganic mercury in hair accounted for a larger proportion of total mercury than at higher concentrations. For hair samples in which the total mercury concentration was above 0.3 μg/g, MeHg accounted for 81% of total mercury. This is in good agreement with data reported for fish consuming populations elsewhere (WHO 1990). As fish consumption is the only significant source of exposure to methylmercury, these data indicate that most of the mercury exposure in the NJ pregnant population is due to methylmercury, and results from fish consumption.

The extreme southern portion of the state was not represented in this study and, since the southern coastal areas support active recreational and commercial marine fisheries, some caution is required in generalizing from these data. In addition, this study was intended to represent MeHg exposure in the general NJ pregnant population. It was not intended to specifically capture that fraction of the population with a high frequency of fish consumption. Such individuals in NJ and elsewhere have been seen with increasing frequency by physicians, but their occurrence in the population and their levels of exposure have not been quantified. Nonetheless, it appears that in NJ, as well as nationally, 10% or more of pregnant women and women of childbearing age have mercury blood concentrations greater than 1.0 μg/L (ppb) and hair mercury concentrations greater than 1.0 μg/g (ppm). Methylmercury appears to account for nearly all of these elevated exposures.

2. NJDEP/Eagleton Study of Fish Consumption in NJ

In 1993, NJDEP-DSRT and the Eagleton Institute of Rutgers University, New Brunswick, NJ conducted a random digit dialing survey of 1,000 NJ households. Sampling was stratified to provide equal numbers of men and women respondents and to proportionally represent NJ by county. The completion rate was 72%. Respondents provided information on a per-meal basis on fish and seafood (henceforth referred to simply as "fish") consumed during the previous seven days. Information was obtained on the species and/or type of fish (e.g., fish sticks) consumed, and the portion size. Portion size was either obtained directly in ounces or was estimated from the reported portion size. In addition, respondents were asked to provide information on the usual frequency of fish consumption by themselves and their households. The data were analyzed separately for the total sample and for women 18-40 as an estimate of women of childbearing age.

Of the 1,000 respondents, 933 reported fish consumption at least a few times per year. The mean portion size was estimated at 6 oz. (168 g; 90th percentile = 284 g). The most commonly consumed fish was tuna (canned and fresh), followed by shrimp and flounder/fluke. These three species accounted for 45% of all reported fishmeals. Shark and swordfish, the fish which have among the highest mercury concentrations, accounted for less than 2% of the reported meals. The reported frequency of consumption during the seven-day recall period by those respondents who actually consumed fish during that period is given in Table 2.30 and Figure 2.8..

Table 2.30. Number of Meals Reported by Consumers During the Seven-Day Recall Period (Stern et al. 1996).

Number of meals eaten during the 7-day recall period	Percent of total respondents consuming fish during the recall period	Cumulative percent of total
1	42	42
2	30	72
3	17	89
4	5	94
5	2	96
6	2	98
7	1	99
>7	1	100
Total	**100**	-

It is important to note that 2% of fish consumers reported eating fish one or more times a day over the seven-day period. Table 2.30 gives the usual consumption of fish reported among all respondents. Approximately 7% of those surveyed reported that they never ate fish.

Table 2.31. Reported Usual Consumption of Fish Among 1,000 Survey Respondents Who Reported at Least Some Fish Consumption (Stern et al. 1996).

Usual frequency of fish consumption	Percent of total respondents
more than twice per week	7
1-2 times per week	39
once every two weeks	19
once per month	22
"a few times per year"	14

The average daily mass of fish consumed was estimated from the combination of information on frequency of consumption during the recall period with reported portion size for each meal (Table 2.32. These data reflect fish consumers only.

3. Rutgers' Arthur Kill Study of Fishermen

May and Burger (1996) interviewed 269 fishermen in the Arthur Kill, Raritan Bay, and north Jersey shore in mid 1994. The average fish consumption was estimated at 52.8 g/day with a maximum of 220 g/day, very close to the 50 g/day reported by Stern et al. (1996). In the Arthur Kill 30% of fishermen ate fish more than 4 times/month.

(NHANES), which includes dietary questions. In NHANES I (NCHS 1978), conducted in the early 1970's, 45% of the population reported eating fish-and-shellfish "seldom or never". There was no difference by race or gender. Anderson and Rice (1993) suggested that the average rate of fish consumption rates in New Orleans was higher than these values. The US Department of Agriculture conducted the Continuing Survey of Food Intake by Individuals (CSFII), a national food consumption survey. Data from 1989-1992 was analyzed to yield an average US fish consumption rate of 15.6 g (about 2/3 of which were salt water fish; Jacobs et al. 1998).

Table 2.32. Distribution of Estimated Average Daily Fish Consumption Among NJ Consumers (estimated in g/day). (Stern et al. 1996).

Percentile of the population	All adult fish consumers (g/day)	Fish consuming women 18-40 years old (g/day)
Mean	50.2	41.0
5th	9.1	7.0
10th	12.2	10.3
25th	24.3	20.3
50th	32.4	28.0
75th	62.1	48.6
90th	107.4	88.1
95th	137.7	106.8
99th	210.6	142.3

While some data on fish consumption by localized communities are available, few data giving fish consumption rates for large populations are available. Table 2.33 provides a comparison of NJ fish consumption rates to fish consumption rates estimated for the entire US population. While there may have been increases in fish consumption over the periods spanned by these estimates, and while the *per capita* estimates in the CSFII database are difficult to compare directly with the NJ estimates, which reflect rates only for those who consume fish, it appears that fish consumption in NJ is greater than in the US as a whole.

The NJ fish consumption survey data were also used to estimate methylmercury (MeHg) exposure (Stern et al. 1996). MeHg exposure was estimated by assigning characteristic mercury concentrations to each species of fish consumed at each reported meal. Selection of characteristic mercury concentrations was somewhat uncertain because of the limited and/or outdated nature of the database on mercury concentrations in commercial fish (see Chapter 4, Section B.3)

Table 2.33. Comparison of Fish Consumption Rates Estimated in NJ and Nationwide.

		All Adults		**Women of Childbearing Age**	
Fish Consumption Study	**Period of Data Collection**	**Mean Consumption Rate (g/day)**	**90th Percentile Consumption Rate (g/day)**	**Mean Consumption Rate (g/day)**	**90th Percentile Consumption Rate (g/day)**
NJ all fish (Stern et al. 1996)	1993	50	107	41	88
NJ saltwater finfish only (Stern et al. 1996)	1993	40	75	--	--
NJ - Arthur Kill, Raritan Bay (North Coastal) (May and Burger 1996)	1994	52.8	maximum = 220 (90th Percentile not reported)	--	--
Middle Atlantic	1973-4	12	27 [b]	--	--

Region (incl. NJ) - saltwater finfish only (Rupp et al. 1980)[a]					
US Overall (Rupp et al. 1980)	1973-4	11[b]	24 [b]	--	--
US Overall (Market Research Corp. of America - Cramer 1994)	1977-87	35 [c]	72 [c]	--	--
CSFII (Jacob et al. 1998)	1989-91	18[b,d]	60[b,d]	14[b]	47[b]

a. *Data from Rupp et al. (1980) are reported as desegregated into saltwater finfish, freshwater finfish, and shellfish, and cannot be re-aggregated. Comparison to NJ data are therefore on the basis of saltwater finfish only.*

b. *CSFII and Rupp et al. data are per capita estimates and are likely to underestimate consumption by consumers as reported in the other studies.*

c. *18-44 years old.*

d. *Unweighted average of "15-44 years old", and "45 years old and older" categories.*

4. Estimation of Methylmercury Exposure from Fish Consumption

Characteristic mercury concentrations were adjusted to account for a clear trend in more recent (but limited) data toward lower mercury concentrations in a given species. This highlights the need for updated data on mercury levels in commercial fish in NJ. Combining per meal data on mercury concentration, and portion size, gives MeHg intake per meal. Summing MeHg intake per day over the seven day recall period for each consumer gives a distribution of MeHg intake per day (µg/day). Dividing the intake by an assumed body weight (70 kg for all adults or 62 kg for women ages (18-40) converts the intake estimate into a dose estimate (µg/kg-body weight/day). Table 2.34 gives the distribution of estimated MeHg intake among NJ fish consumers.

Table 2.34. Distribution of Estimated Average Daily MeHg Intake and Dose Among Adult NJ Fish Consumers (Stern et al. 1996).

	Average daily MeHg intake		**Average MeHg dose**	
	(µg/day)	**(µg/day)**	**(µg/kg/day)**	**(µg/kg/day)**
Percentile of the population	**All adult fish consumers**	**Fish consuming women 18-40 years old**	**All adult fish consumers**	**Fish consuming women 18-40 years old**
mean	5.8	4.9	0.08	0.09
5th	0.5	0.4	0.01	0.01
10th	0.8	0.8	0.01	0.01
25th	1.6	1.5	0.02	0.02
50th	3.1	3.2	0.04	0.05
75th	5.8	5.4	0.08	0.09
90th	13.1	10.8	0.19	0.17
95th	21.1	15.7	0.30	0.25
99th	49.9	26.5	0.71	0.43

Table 2.35 presents a comparison of the distribution of MeHg intake in NJ with nationwide estimates presented by the USEPA in its Mercury Report to Congress (1997e). Both estimates are based on linking data on fish consumption with data on characteristic mercury levels in fish by species.

Table 2.35. Comparison of Consumption Estimates of Daily Dose of MeHg to Fish Consumers in NJ and Nationwide (µg/kg/day).

Percentile of the population	**NJ adult population** [a]	**US Adult population** [b]	**NJ women of childbearing age (18-40 years old)**[a]	**US women of childbearing age (15-44 years old)**[b]
50th	0.04	0.02	0.05	0.01
75th	0.08	0.05	0.09	0.03
90th	0.19	0.13	0.17	0.08
95th	0.30	0.22	0.25	0.13
99th	--	--	0.43	0.37

a. from Stern et al. 1996
b. from USEPA (1997e) - unweighted average data by ethnic/racial groups

Based on estimates from fish consumption, it appears that fish consumers in NJ are exposed to an average daily dose of MeHg which is 1.5 to more than 3 times *higher* than that seen nationwide. The apparently elevated MeHg exposure in NJ compared to national estimates is consistent with the apparent elevated rate of fish consumption in NJ. It is notable that the greatest differences between estimated NJ and national exposure levels are seen among women of childbearing age. As discussed previously, estimates of MeHg exposure among NJ pregnant women based on MeHg in hair were consistent with national estimates from CDC/NHANES with both studies showing greater than 10% of pregnant women or women of childbearing age exceeded a mercury concentration of 1 µg/g in hair. From the available data, it is difficult to determine precisely how much greater than 10% pregnant women or women of childbearing age exceed this concentration either in NJ or nationally. Therefore, consistency of the NJ and national estimates based on mercury hair concentration does not necessarily contradict the observation from fish consumption data suggesting that MeHg exposure in NJ exceeds exposure nationwide.

The EPA RfD for MeHg is 0.1µg/kg/day. It is likely that about 25% of women of childbearing age exceed this amount.

5. *High End Fish Consumption and Methylmercury Intake*

It is important to emphasize that these data show that a small but significant fraction of the NJ pregnant population consumes fish at a much greater rate than the average NJ resident. Based on the data presented by Stern et al. (1996), about 5% of the total NJ population consumes about three times more fish than the average US resident. On average, women of childbearing age appear to consume about 20% less fish than the total population. To the extent that this sample succeeded in representing NJ's population there could be about 150,000 NJans who consume fish at least daily.

Likewise, the data on mercury exposure in the NJ population (see Tables 2.35 and 2.36) shows that for all adults as well as for women of childbearing age, the estimated MeHg dose for the top 5% of the population (i.e., the 95th percentile) is 3-4 times the mean dose in the population. These indicate that a significant fraction of the NJ population has a considerably elevated exposure to MeHg. Further analysis of these data indicates that elevated MeHg exposure in this population can result from either moderate rates of consumption of fish with high mercury concentration (e.g., shark, swordfish), or from high rates of consumption of fish with moderate mercury concentrations. The latter is a much more common cause of high exposure in women of childbearing age, very few of whom reported consumption of high mercury concentration fish. Thus frequent (almost daily) consumption of fish represents a larger part of the high exposure group, than those who preferentially consume high amounts of mercury.

6. *Summary and Conclusions: Methylmercury Exposure from Fish Consumption in NJ*

A very high proportion of the adult NJ population eats at least some fish. The mean fish consumption rate for those who eat some fish is estimated to be 50 g/day for all adults and 41 g/day for women of childbearing age. However, the top 5% of fish consumers consume fish at about three times this mean rate. These rates appear to be considerably greater than national consumption estimates derived largely in the 1970's and 1980's, but are comparable to those of South Carolina fishermen interviewed in 1997 (Burger et al. 1998). This discrepancy may reflect a general increase in fish consumption over the last 10-20 years. The estimated mean daily MeHg dose for fish consumers is 0.08 µg/kg/day for all adults and 0.09 µg/kg/day for women of childbearing age. However, 5% of fish consumers are estimated to have MeHg exposures 3 times the mean dose. The distribution of MeHg exposures in NJ may be 1.5-3 times that estimated for US fish consumers nationally.

The great majority of pregnant women in NJ appear to have low levels of exposure to mercury in general and to MeHg in particular. However, a small but significant fraction of the pregnant population does have elevated exposures to MeHg from fish consumption. Blacks and those with middle class incomes appear to be at lowest risk of exposure. No data are available on mercury levels in people in NJ who regularly consume large amounts of fish.

C. Exposure to Elemental and Inorganic Mercury

1. *Residential Exposure to Elemental Mercury*

Residential exposure to mercury has occurred from a variety of sources including mercury-containing paints, electrical devices, gas meters, thermostats and thermometers, as well as mercury used for recreational or cultural purposes. Recently, significant spills of mercury have occurred during the removal of old gas meters from basements, and in some cases homes are not remediable and have been condemned. Children occasionally find mercury and bring it home to play with. The cultural practice of Santeria includes some uses of mercury, such as sprinkling mercury around a residence, on babies or in cars, and carrying it in an ampule as a good luck charm.

a. *Residential Exposure from a Former Industrial Building*

Probably the most serious documented case of residential mercury exposure in NJ is the residual contamination in the former General Electric/Cooper-Hewitt mercury vapor lamp factory at 720 Grand Street in Hoboken. This highly contaminated building was eventually sold to a partnership of artists, who renovated the building into a series of apartment/studios, in which they lived and worked. Although some mercury was encountered during the renovation, a consultant reassured the occupants that the mercury could be remediated. When mercury droplets were discovered in the kitchen of an apartment with a small child, the health department was contacted. This initiated a series of investigations that showed that 2/3 of the occupants had elevated mercury levels in their urine and that some of the apartments had mercury levels in air that exceeded the 40 hour time weighted average occupational Permissible Exposure Limit of 50 $\mu g/m^3$ for mercury. (Orloff et al. 1997). The mercury concentration in the air of the apartments exceeded the CDC Minimal Risk Level for inhalation. All occupants were evacuated, and, after a series of studies, the USEPA concluded that the building could not be remediated. Some adverse reproductive and childhood nervous system conditions were possibly associated with elevated mercury levels. Neurobehavioral testing revealed impairment of fine-motor coordination in the subgroup with urine mercury above the median value. The evacuation necessitated by the high mercury levels produced severe psychological distress (Fiedler et al. 1999). Eventually the artists received from the government, but not from the responsible parties.

b. Ingestion and Inhalation Exposure from Drinking Water

As discussed in section Chapter 7 of Vol. II, mercury has been detected above the maximum contaminant level (MCL) for drinking water (2 µg/l) in some private wells in southern NJ. The highest total mercury concentration in wells was 36 µg/l and the mean total mercury concentration among those wells exceeding 2 µg /l was 8 gµ/l (Murphy et al. 1994). Although measurable organic mercury (presumably methylmercury) was detected, it was present at a very low level. However, a small fraction of the total mercury in this water has been identified as "volatile mercury", which is assumed to be elemental (Murphy et al. 1994). The mean concentration of volatile mercury in these southern NJ wells was 0.2 µg /L (maximum=0.4 µg /L). For water containing 5.0 µg/L or higher, the RfD of 1.0 µg/kg/day would be exceeded. Even when people stop drinking this water, they may continue to be exposed. Low levels of inhalation exposure to mercury occur during cooking or dish washing, but the primary source of inhalation exposure to mercury in drinking water is through showering.

c. Shower Exposure

Hg^0 is poorly absorbed through the skin, and dermal absorption during a shower is not expected to be significant. The USEPA reference concentration (RfC) for mercury vapor is 0.3 µg/m^3. This is defined as the concentration of Hg^0 in air to which even the most sensitive individuals could be exposed on a 24-hour-a-day bases with no significant adverse effects. Assuming an inhalation rate of 0.63 m^3/hr with low-moderate exertion (US EPA 1990), the RfC corresponds to a 24-hour dose of 4.5 µg Hg^0. During showering, warm water passes through the nozzle forming a fine spray, which facilitates volatilization, releasing Hg^0, which can be inhaled. Since bathrooms are often not well vented (especially during showering), the concentration of Hg^0 in the air can continue to increase over the course of the shower.

The extent to which Hg^0 will volatilize from shower water depends on a number of factors including the water temperature, the type of shower nozzle, and the duration of showering. Assuming that 50-100% of the Hg^0 in the shower water will volatilize to the air, and employing reasonable assumptions for shower duration, bathroom size, bathroom ventilation rate, and inhalation rate, it can be predicted that for the maximum reported Hg^0 concentration in private well water, the amount of Hg^0 that would be inhaled over the course of a shower would exceed the dose corresponding to the USEPA RfC. If only 10% of the mercury volatilizes, the showering dose of Hg^0 would not exceed the dose corresponding to the RfC.

d. Indoor Paint

Mercury compounds, particularly phenyl mercuric acetate (PMA), were added to water-based paints to prolong shelf-life by controlling bacterial fermentation in the can and to retard fungus attacks upon painted surfaces under damp and humid conditions. In July 1990, partly in response to an incident in 1989 in Michigan when a 4-year old boy suffered mercury poisoning after mercury-containing paint was applied to the interior of his home (Beusterien et al. 1991), all registrations for mercury biocides used in paints, except for PMA, were voluntarily cancelled by the registrants. In May, 1991, EPA announced the voluntary cancellation of the remaining PMA registrations, which were for exterior paints and coatings (USEPA 1992). Several studies have indicated that when mercury-containing coatings and paints were applied, the painted surfaces released elemental mercury to the air (Beusterien et al. 1991; Agocs et al. 1990).

Estimating the amount of mercury released from surfaces to which this paint was applied requires an estimate of the half-life of the mercury in the painted surface. One estimate is that the half-life was approximately one year (Minnesota Pollution Control Agency 1998). It appears from some data that the half-life could have been somewhat longer (Agocs et al. 1990). If a half-life of 1.5 years is assumed, and first-order exponential decline of emissions over time, emissions from a surface painted in 1991 would today be 1% of what they were then. (Emissions from a painted surface can be assumed to be proportional to the amount of mercury in that surface. Assuming first-order exponential decline of the amount of mercury in a painted surface, and a half-life of 1.5 years, the amount of mercury remaining ten years after application, M_{10}, can be expected to be equal to $M_0 \times e^{-k \times 10}$, where M_0 is the initial amount, and k is 0.46 (corresponding to a 1.5 year half-life). If M_0 is set as 1, then M_{10} equals approximately 0.01), and will continue to decline to negligible quantities over the next few years. Therefore, it is unlikely that emissions of mercury from painted surfaces present significant risk today.

Inorganic mercury compounds, such as mercury oxide (red oxide of mercury) were also used as paint pigments, but the main exposure would have been to those who manufactured the pigment and fabricated the paints.

e. Cultural Practices

Because of its unique properties, elemental mercury has been used in a variety of cultural practices (e.g., Santeria) or simply as a good luck charm or a curiosity. These practices are apparently widespread in people who have immigrated from the Caribbean. Some people carry capsules of elemental mercury as good luck charms. In other practices mercury may be sprinkled in homes, over babies or in vehicles. Some Santeria practices can yield mercury levels far above the occupational Permissible Exposure Limit. Interviews with practitioners indicate that they are aware that mercury is hazardous, but unaware that in the absence of tangible vapors there is an inhalation risk (Riley et al. 2001). The authors concluded that most such cultural uses of mercury involve the carrying or storage of mercury in sealed containters or amulets. Practices involving sprinkling of mercury appear to be much less common. The authors argue that attempts to tightly regulate such practices will result in the practices being driven "underground" and conducted with much greater secrecy, making even non-regulatory outreach difficult. Riley, et al. (2001) recommend outreach to practitioners and community leaders as well as botanica personnel and those who actually use the mercury. Evaluation of existing brochures and printed material is desirable. Riley, et al. argue that regulating this practice will merely drive it underground, a conclusion that the Task Force reached as well. The extent of this practice in NJ and the resulting levels of mercury exposure will need to be determined, and an educational program mounted to curtail such uses or reduce exposures as much as possible. In addition to the acute exposure during certain ceremonies, the practice may leave residual droplets of elemental mercury, which will continue to evaporate, and may lead to seriously elevated concentrations of mercury in indoor air, which will persist for years. The USEPA has developed a working group to examine the extent of these practices and to provide outreach to reduce exposures.

f. Summary and Conclusions

In at least one location in Hoboken, NJ, residents in an apartment building renovated from a former mercury vapor lamp factory, were exposed to significant levels of mercury, which appear to have resulted in adverse health effects in those exposed at the highest levels. In homes receiving ground water contaminated with mercury, there may be volatilization of elemental mercury during showering or cooking. The potential for exposure varies depending on the fraction of the total mercury is present as elemental mercury, the total mercury concentration, water temperature, nozzle type, ventilation, and exposure duration. Under some exposure scenarios, the safe dose corresponding to the EPA RfC for Hg^0 would be exceeded. There are currently insufficient data relating to the extent of contamination of well water by mercury to estimate the number of individuals or households potentially exposed to such levels of Hg^0. The exposures to elemental mercury in homes continue to occur from spills or deliberate introduction.

2. NJ Occupational Exposures

In the mid-20th century, NJ was home to a variety of mercury-using and mercurial-producing industries including manufacturers of thermometers and electronics, paints and pigments, and organomercurial biocides for use in anti-fouling paints and pharmaceutical products. Although the number of plants and workers engaged in mercury-related commerce in the 1940-1970 period is not documented, most facilities were located in the industrialized areas of northern NJ, particularly the Newark-Paterson region. Plants varied in age and size, with older, more economically marginal operations potentially causing exposures internally to workers as well as externally to neighboring communities and ecosystems.

By the early 1970's, companies were beginning to pay more attention to mercury, partly due to the relatively high price at the time and also due to increasing regulatory concerns of the newly-formed Environmental Protection Agency and the Occupational Safety and Health Administration. Recycling mercury became both cost-effective and fashionable. At the same time, however, many hazardous operations were being shipped overseas to countries less environmentally conscious and that offered inexpensive labor. Mercury industries began to follow suit. The banning of mercury in anti-fouling paints led to the demise of some NJ industries that produced organomercurials specifically for that purpose.

In the 1960's and 1970's, the Division of Environmental Health Sciences at Columbia University provided industrial hygiene and occupational nursing and medical services to several mercury-using industries. In that period, it was not uncommon to find air levels of mercury that exceeded the Recommended Exposure Level (National Institute for Occupational Safety and Health) of 0.025 mg/m^3. Workers' blood mercury levels sometimes exceeded 100 μg /L, but most plants had workers with blood levels between 10 and 40 μg/L, which is indicative of excessive exposure, but would not necessarily signify a health risk. Certain factories found it difficult or not cost-effective to institute good industrial hygiene and environmental engineering controls. The most extreme example in NJ was the Ventron Corporation, which closed its Moonachie Plant in 1973. Subsequently the buildings were destroyed, leaving behind one of the world's great legacies of mercury contamination. More than a quarter of a century later, the contamination at the Ventron site and in adjacent Berry's Creek remains. [see Berry's Creek section vol 2, chapter 8]

There remain some industrial uses of mercury in NJ, for example, thermometer manufacture. Many dental offices continue to use mercury amalgam fillings, thereby potentially exposing office staff. However, most uses of mercury (thermometers, thermostats, mercury switches, batteries, dental amalgams, and fluorescent bulbs) are being examined, with model legislation proposed in many states to ban or reduce most of those uses. There continues to be the opportunity for occupational exposures in health care facilities and in dental offices, although educational programs and spill cleanup procedures have greatly reduced these workplace exposures. A new workforce involved in the assessment and management of mercury spills and wastes is also potentially exposed, but should be well protected by intensive education, training, protective equipment and monitoring.

D. Risk Assessment and Reduction

1. Assessment of Risk to NJ Fish Consumers

At present, there is no simple relationship between methylmercury exposure and the risk of adverse effects. The role of genetic susceptibility and concomitant exposures is unknown. There are, however, several benchmarks against which this risk can be compared. These are described below.

The most significant risk from mercury in general, and to fish consumers in particular, is the potential for methylmercury (MeHg) to cause adverse effects to the developing fetal brain. While the exact maternal dose corresponding to a threshold for such effects is unknown, several possible benchmarks of risk can be identified for assessing the potential for significant risk.

a. EPA Reference Dose

The current USEPA Reference Dose (RfD) for MeHg is 0.1 µg/kg/day (US EPA 1997e). This has recently been reviewed in detail and endorsed by the National Research Council (an arm of the National Academy of Sciences) (NRC 2000). This value specifically addresses neuro-developmental effects to the fetus through maternal exposure. The US EPA RfD is essentially the same as NJDEP's acceptable daily intake of 0.07 µg/kg/day used in the derivation of fish consumption advisories. The RfD is defined as "...an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." (US EPA 1999). As such, the RfD for MeHg represents a dose at or below which adverse effects on the developing brain are not expected to occur. The risk of adverse effects at doses above the RfD cannot be predicted on the basis of the RfD itself. The RfD incorporates some margin of safety, but with doses much above the RfD there is the potential for harm.

The Hazard Quotient is calculated by dividing the estimated daily intake by the RfD. An HQ > 1 is considered unacceptable. One estimate of the risk from MeHg exposure to NJ fish consumers is the fraction of the population of pregnant women, or women of childbearing age in NJ, who have MeHg exposures which exceed the RfD. There is also a potential for risk to the general population of fish consumers in NJ from MeHg. MeHg can produce adverse neurologic effects in adults, which are qualitatively different from those produced in the developing fetus. The previous EPA RfD for MeHg (0.3 µg/kg/day), derived from the poisoning episodes in Japan and Iraq addressed adult neurotoxicity rather then neuro-developmental toxicity. Although EPA has officially replaced this RfD, it is still being applied to those adult endpoints. Therefore, analogous to the risk to pregnant women in NJ, one estimate of the risk of MeHg to the general population is the fraction of the adult population, which exceeds this "adult" RfD. Caution is needed, however, since recent studies of neuropsychological function in adults exposed to low levels of MeHg in the Amazon region of Brazil (Lebel et al. 1996) suggest that subtle effects may occur at exposures below 0.3 ug/kg/day. Furthermore, the recent NRC recommendation, while confirming the value of the current RfD suggested redefining the uncertainty factor adjustments in the RfD derivation to include additional possible "adult" health effects such as cardiovascular and immunotoxicity which may occur at exposure levels below those resulting in fetal neurotoxicity. Thus, if the USEPA adopts the RfD approach recommended by the NRC, the new RfD would apply equally to adults and the developing fetus. This would supercede the use of the previous "adult" RfD for assessing risk to adult fish consumers.

At the current time, there are no data, which allow the direct estimate of the specific risk to children from post-natal exposure. However, since the nervous system continues to develop after birth, it is prudent to assume a similar sensitivity, and hence, risk to children has been addressed indirectly by application of the RfD for pregnant women. Therefore, no attempt will be made to estimate the risk from MeHg resulting from childhood exposure.

b. Comparison to Published Studies

Another approach to estimating risk of MeHg to NJ fish consumers is to compare current exposure to the lowest levels of exposures which have been associated in various studies with measurable effects. This approach is difficult for several reasons, however. In a study of New Zealand fish consumers (Kjellström et al. 1986) subtle developmental effects in six-year old children were found to be associated with maternal exposure during gestation corresponding to maternal hair mercury levels >6 μg/g. In the Faroe Islands study, Grandjean et al. (1997) reported a significant relationship between subtle adverse nervous system effects in seven-year old children and the maternal hair mercury levels. The geometric mean mercury hair level in this study population was 4.3 μg/g. A similar study in the Seychelles where people also eat a lot of fish, did not find neurodevelopmental impairment.

The NRC (2000) committee conducted a benchmark dose analysis of these data. This analysis predicted that infants born to mothers with hair levels of 10 μg/g were twice as likely to fall into the lowest 5% of performance on a battery of neurodevelopmental tests. Based on these comparisons, we can estimate that maternal hair mercury levels of 4-6 μg/g corresponds to the lowest levels of exposure at which a risk of adverse effects may be detected in a population (rather than on an individual basis).

As discussed previously, there are two sources of data on methylmercury exposure in the NJ population: the study of MeHg in the NJ pregnant population (based on hair and blood mercury, Stern et al. 2001), and the study estimating daily MeHg intake based on fish consumption (Stern et al. 1996). Since the concentration of mercury in hair is pharmacokinetically related to the daily MeHg intake (Stern 1997), it is possible to express both estimates of exposure in terms of estimated intake in micrograms of MeHg per kilogram of body weight per day (μg /kg/d), or in terms of hair mercury concentration (ppm or μg/g).

Based on the data from Stern et al. (1996, 2001), Table 2.35 presents the estimated percent of the NJ population of fish-consuming pregnant women and fish consuming women of childbearing age exceeding the benchmarks of risk discussed above (expressed as intake dose (μg/kg/day) and, equivalent hair mercury concentrations (ppm)). For the two roughly equivalent categories of pregnant women and women of childbearing age in NJ, there is a reasonably close agreement that 10-20% of the at-risk population has exposures that exceed the current USEPA RfD for MeHg (which includes a 10-fold uncertainty factor adjustment) and thus are exposed above a level which can be considered safe. There is also agreement that approximately 1-3% of that sub-population is exposed to MeHg at levels at which the risk of adverse effects may become discernable. Both NJ studies also predict that less than 1% of this population has exposures, which would result in a doubling of the likelihood of children performing below the 5th percentile of neurologic performance. In addition, the data indicates that 5% of the adult fish-consuming population has an exposure, which exceeds the USEPA 'RfD' applicable to the adult population (0.3 μg/kg/d).

Table 2.36. Estimated Percent of the NJ Population with MeHg Exposures Exceeding the Selected Risk Benchmarks.

Risk Benchmark	**Percent of Pregnant Women in NJ Exceeding the Benchmark** (Stern et al. 2001)	**Percent of Women of Childbearing Age in NJ Exceeding the Benchmark** (Stern et al. 1996)
Current USEPA RfD for methylmercury (0.1 µg/kg/day - ~1 µg Hg/g hair)	10-15%	21%
Average maternal hair mercury in Faroe Is. - 4 µg/g (~0.4 µg/kg/day)	1-2%	1-3%
Doubling of proportion of children in the lowest 5% of neurologic performance (~4 µg/kg day)	<1%	<1%

2. *Clinical Cases in NJ*

The risks from consuming fish containing methylmercury are not hypothetical, nor are they confined to pregnant women and their fetuses. Recently, the Clinical Center at the Environmental and Occupational Health Sciences Institute has identified several individuals with evidence of early, clinical toxicity from mercury associated with elevated blood and hair levels of mercury, and self-reported fish consumption. Two examples are summarized below:

A 55-year old female musician with strong interest in health and healing, noticed difficulty in playing her guitar and also in performing artwork. Analysis revealed a hair mercury content of 15.7 µg/g. She had abandoned red meat and chicken for health reasons five years earlier, and ate between 10 and 12 meals of fish per week, more than half of which were shark and swordfish. After four months of avoiding fish, her hair mercury level had declined to 7.0 µg/g and her fine motor coordination had returned to an apparently normal level.

A 6-year old girl developed an uncontrollable "tic" of her neck and shoulders. Extensive neurologic evaluation found no abnormalities, but her blood mercury level was 24 µg/l and her hair mercury level was 13 µg/g. Her mother reported that she ate 7 or more meals of canned tuna per week (totaling about 36 ounces/week). After three weeks of avoiding tuna fish, her blood mercury had fallen to 21 µg/l. Her "tic" disappeared.

Such cases indicate that although sporadic, there are children and adults in NJ who consume sufficient quantities of fish to result in excessive mercury exposure, even to the point of being symptomatic.

3. *Treatment of Methylmercury Poisoning*

The use of chelating agents (usually containing sulfhydryl groups) is a generally accepted approach to treating heavy metal poisoning, particularly when there are high levels of metals circulating in the blood stream. The utility of chelation to treat chronic, low level exposure, is controversial. Treatment was beyond the scope of the Task Force investigation, and people who are concerned about exposure to heavy metals in general or mercury in particular, should consult an experienced medical professional, but should be aware of the fact that inappropriate use of chelation or certain other treatments may be harmful.

4. Summary and Conclusions: Risk Assessment and Reduction

There is no definitive way to estimate the percentage of babies born in NJ that will experience adverse effects or subtle impairment because of pre-natal mercury exposure. However, there are several benchmarks against which risk can be gauged and there are two studies that permit estimates of MeHg exposure in NJ fish consumers. It appears that 10-20% of the pregnant population in NJ have exposures that exceed a clear no-effect level (i.e., the USEPA RfD), and that 1-3% have exposures at which adverse effects may be observed. In addition, it appears that 5% of the general adult fish consuming population in NJ have exposures that exceed a clear no-effect level for MeHg (i.e., the previous USEPA RfD for adult health effects). These observations indicate that while the great majority of NJ fish consumers are at low risk from MeHg exposure, a small fraction of the population may have a significant level of risk. The results are comparable to those recently reported in the CDC/ NHANES IV assessment.

None of these studies have targeted high-end consumers, people who deliberately eat large quantities of fish, often 10 or more meals per week. In NJ, some adults and children eat sufficient amounts of fish to develop clinical signs of methylmercury poisoning.

Evidence from a limited number of medical case studies of high end NJ fish consumers suggest that subtle but clinically detectable effects from MeHg resulting from fish consumption are present in the population.

E. Fish Consumption Advisories and Outreach

1. Current Advisories

Most states have issued fish advisories for certain waters or species, and most advisories nationwide are based on or mention mercury. In July 1994, the NJ Department of Environmental Protection (NJDEP) and the NJ Department of Health (NJDOH), now the NJ Department of Health and Senior Services (NJDHSS), issued fish consumption advisories based on mercury for two recreationally important freshwater gamefish - Largemouth Bass and Chain Pickerel. Both species are indigenous to NJ and are among the most popular species sought by the state's anglers. The advisories were based upon research conducted by the Academy of Natural Sciences - Philadelphia (ANSP), in collaboration with NJDEP, which identified concentrations of mercury in the edible tissues of these two species which exceeded the NJ's risk-based human health criteria (ANSP 1994, TIBC 1994). Although NJ has advisories for marine and estuarine fish based on PCBs, dioxins and chlordane, there are currently no mercury-based advisories for marine fish in NJ.

In January, 2001, the USFDA issued a revised fish advisory for pregnant women, women of childbearing age, and nursing mothers, not to consume any shark, swordfish, king mackerel, or tilefish, and to limit consumption of commercial fish to 12 ounces per week.

(http://www.fda.gov/bbs/topics/ANSWERS/2001/advisory.html). The EPA likewise revised its advisory for non-commercial freshwater fish to limit consumption to one meal per week for the same population, including young children.

The following table (Table 2.36) delineates the levels in fish, which correspond to different "advice" for high-risk groups and others. These numbers are the basis for the current NJ consumption advisories for Largemouth Bass and Chain Pickerel. Of course, consumers currently have no way of telling what the level is in a particular fish, hence the need to provide a comprehensive data base of characteristic levels and distributions for commonly consumed fish including commercial fish. Currently, limited guidance and few current data are available from the federal government. A colorimetric test [not available as of July 2001] is being devised which would turn color if fish contain more than 0.5 ppm of mercury.

Table 2.37. Criteria for Mercury-Based Fish Advisories, Assuming that Different Fish Have Mercury Concentrations in the Very High, High, Moderate, and Low Range.

	High Risk Groups[1]	**General Population**[2]
Very High Range Do Not Eat	> 0.54 ppm	> 2.81 ppm[3]
High Range May eat once a month	0.19-0.54 ppm	0.94-2.81 ppm
Moderate range May eat once a week	0.08-0.18 ppm	0.35-0.93 ppm
Low Range No Restriction	< 0.07 ppm	< 0.34 ppm

[1] *Women who are pregnant or planning to get pregnant soon, nursing mothers and children under 5*

[2] *Other adults and adolescents*

[3] *Some samples of shark and swordfish exceed the 2.81 ppm level and almost all exceed 0.54 ppm*

2. *Outreach for Advisories*

The NJDEP, Division of Fish and Wildlife (DFW) includes the current advisories in their publication titled, *NJ Fish and Wildlife Digest*, listing fishing regulations for recreational anglers (DFW 2000). The DFW digest is issued three times a year and some issues contain the most recent updates of the fish consumption advisories. In addition, the DFW provides advisory information to anglers and posts warning signs in all public waters outlined in the digest. In 1997, NJDEP and DHSS developed a brochure entitled *A Women's Guide to Eating Fish and Seafood, What You Should Know If You Are: Pregnant, Planning to Be Pregnant or Have a Young Child.* The brochure provides valuable fish consumption advice, outlines the current consumption advisories, and offers other health-related information to pregnant women. This brochure, printed in English and Spanish, was distributed to over 6000 obstetrical offices and clinics throughout the state and is available through NJDEP and DHSS.

As a supplement to the brochures, DSRT has also produced, "The Woman's Health Video". This 11-minute video describes the waters under advisory, the species affected and steps that should be taken to avoid exposure to chemical contamination for women and pregnant women. It also outlines ways to properly prepare fish and shellfish in order to reduce consumption of contaminants, which may occur in these foods. The video is available from the DEP Division of Science, Research and Technology at 609-984-6070.

Finally, from 1996 through 2000, the NJDEP sponsored a Harbor Watershed Education Urban Fishing Program. This educational program is aimed at area youths in the 5th and 6th grades. It provides detailed information of the ecology of the waters under advisory introduces students to the affected species and discusses healthy ways to participate in recreational fishing.

The NJDEP and NJDHSS provide information on these fish consumption advisories through several avenues of outreach. When new advisories are issued or revised, the NJDEP distributes information packets and press releases to all newspaper, radio and television outlets in the NJ, NY and Philadelphia metropolitan area. This distribution is often picked up by news wire services such as Associated Press and United Press International. In 1995, NJDEP produced a pamphlet titled, *A Guide to Health Advisories for Eating Fish and Crabs Caught in NJ Waters*, outlining all of the state's fish consumption advisories (including, but not limited to mercury), important health information and preparation and cooking guidelines for those species under advisement (DSRT 1995). In addition, information on fish consumption advisories can be found on the DSRT website: **http://www.state.nj.us/dep/dsr/njmainfish.htm.**

a. Efficacy of Advisories

The mere existence of advisories does not assure that the information will reach targeted populations or that the information will be heeded. Several studies in NJ and elsewhere (Burger and Gochfeld 1996; Burger et al. 1998, 1999; May and Burger 1996; Pflugh et al. 1999; Burger and Waishnell, 2001) have shown that many fishermen are unaware of advisories, and that sources of information and knowledge of advisories vary with ethnicity, education, and language. Developing advisories is not a simple matter and conflicts arise over both the economic impacts as well as the risk message. Commercial fishing interests and those with an economic interest in recreational fishing, fisherfolk themselves, and governmental agencies, may have non-intersecting interests. Even different risk assessors (e.g., local, state, and federal) may arrive at different estimates regarding risks and benefits (e.g. Egeland and Middaugh 1997). Resolving such conflicts requires careful consideration of all risks as well as the impact on target populations (Burger et al., 2001c). Moreover, fishermen may be more willing to trust a lifetime of experience, and their own personal perceptions of fish quality, rather than heed warnings about contaminants that they cannot see, taste, or smell (Burger et al., 1998, 1999). Although about 60% of fishermen interviewed in the Newark Bay complex were aware of advisories, most did not heed them and were not concerned about the health effects from eating fish, even species with high contaminant levels (Pflugh et al., 1999). This level may be general since a South Carolina study likewise study reported that 64% of fishermen were aware of advisories, yet often disregarded them (Burger and Waishwell, 2001). Many consumers do not know enough about fish to apply some of the information in advisories, for example, regarding fresh versus salt water fish (Burger and Gochfeld, 1996).

Carefully worded advisories, with a special emphasis on women who are pregnant or about to become pregnant, reassure people about the benefits of fish consumption while encouraging them to minimize consumption of fish that are high in mercury. However, merely issuing advisories is not enough, as shown in an interview study of 300 urban fishermen by Pflugh et al. (1999). They found that most fishermen were either unaware of advisories or had wrong information about them, and that fishermen often ignored advisories, relying on their own perceptions of fish quality. A survey of fishermen in Jamaica Bay, New York found that only 3% were aware of advisories, 83% believed the water was safe and 28% believed they could tell if a fish was "bad" by its appearance (Burger et al., 1993). Unlike fishermen, many fish-eaters did not know enough about fish biology and ecology to correctly interpret terms like marine vs. freshwater fish, predatory fish, and trophic level (Burger and Gochfeld, 1996), nor does fish size connote much to people.

b. Balancing Risks and Benefits

Reducing exposure to MeHg from fish would be much simpler if fish were not also a highly beneficial food. Around the world fish is a crucial source of protein for many populations out of accessibility and economic necessity. Although the number of truly subsistence fishermen in NJ is relatively small, there are over 1 million anglers in NJ and many people who fish recreationally consume large amounts of fish. There are a growing number of people who have chosen to eat primarily fish in lieu of other sources of protein for health reasons.

There is a substantial literature on the health benefits of eating fish, including specific benefits conferred by omega-3 fatty acids, as well as collateral benefits of abjuring unhealthy foods. Ironically, there may be special benefits of fish consumption on fetal development (Olsen et al. 1990), hence the need to balance carefully the risks vs. benefits of fish consumption to this population.

Recent studies suggest that the beneficial effects of consuming fish may be mitigated by their mercury content. In a study of 1,871 Finnish men randomly selected with no heart disease, 194 had heart attacks. Men with the highest percentile (upper 20%) of fatty acids in serum had 44% reduced risk ($p= 0.014$) compared with those in the lowest percentile. Those with mercury in hair less than 2 μg/g had a 67% reduction compared with those who had $Hg>2$ μg/g. The authors concluded: "Our data provide further confirmation for the concept that fish oil-derived fatty acid reduce the risk of acute coronary events. However, a high mercury content in fish could attenuate this protective effect."(Rissanen et al. 2000).

3. Summary and Conclusions: Fish Consumption Advisories and Outreach

The NJDEP and NJDHSS have attempted to inform the public about new and existing fish consumption advisories for mercury and other contaminants in fish. Since advisories alone do not reach or convince all fish-eaters, additional press briefings, press releases and communications through the media have been undertaken to further communicate the existence and purpose of fish consumption advisories to as wide a group of populations as possible. The main audience for most of this information is the pregnant population, women planning to be pregnant or with young children and the recreational anglers of the state. Bilingual brochures have been distributed to populations at risk, but many target populations speak neither English nor Spanish. Advisories are periodically updated and are made available to fishing license-issuing agents for distribution to the angling public. In addition, warning signs are posted and maintained on those affected waterways around the state. Reaching saltwater anglers remains a problem since no fishing license is required, thereby removing one of the important information channels. Research studies continue to provide new approaches to communicating the targeted populations and outreach programs provide a means of encouraging public involvement in the education and protecting the public from the exposure to toxic chemical contaminants. For commercial fish there is limited guidance and little current information on mercury levels in commonly consumed species to help in making informed choices. Fish consumption provides substantial health benefits. In order not to discourage consumers from fish consumption in general, outreach information must be carefully structured and worded to distinguish between low mercury fish and high mercury fish and to encourage the increased consumption of the former especially by high-risk individuals.

F. Recommendations

Expand and periodically evaluate the effectiveness of current outreach, advisories and education efforts to reduce exposures to mercury of sensitive populations, subsistence fishermen, and others that consume large quantities of fish. To accomplish this, NJ should:

- **Increase public awareness of the public health concerns regarding mercury in fish and the need to reduce the emissions and releases to the State's waterbodies.**

- **Expand outreach on fish advisories, particularly for sensitive populations, subsistence fishers, and others that consume large quantities of fish.**

(From Recommendations "I.1. & 2." in Volume 1).

Adequate funding is needed to continue providing the public with brochures, flyers and documents necessary to inform the targeted populations about fish consumption advisories and patterns of exposure to mercury contamination. Classroom education programs, community outreach and angler awareness needs to be encouraged and successful programs should be financially supported. When appropriate, supplemental literature, signs and handouts should be included in outreach program development. In addition, awareness education, instructional demonstrations, video and commercial programming via public service announcements should be incorporated as part of an ongoing effort to provide the public with an adequate measure of protection.

Expand educational programs to inform the public about the need to balance the benefits and risks from fish consumption.

Additional, creative approaches to risk communication should be investigated and funded where appropriate.

It is essential to obtain information about NJans who consume large quantities of fish (above the 95th percentile of consumption). Currently, there are no comprehensive social, geographic, or demographic data that identifies "high end" fish consumers who are the ones at increased risk from methylmercury.

Data are particularly needed to better characterize people living along the coasts or in extreme southern NJ where fish consumption and mercury exposure may be different from that part of the population, which has been characterized to date.

Educational/informational programs should target high-end fish consumers and pregnant women to enable them to choose fish that are low in mercury and perhaps to moderate their fish consumption.

A survey of mercury levels in fish obtained recreationally and available commercially is essential in order to inform consumer choice.

An ongoing monitoring program for mercury and other bioaccumulative toxics should be established for commonly consumed fish species to provide statistically valid data on mercury exposure and trends.

Cases of clinically apparent methylmercury poisoning should be documented and linked to the NJDHSS Heavy Metals Database.

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment, and the exposure pathways. To accomplish this, NJ should: Upgrade procedures used in all monitoring programs to include state-of-the-art analytical methods to provide lower detection limits for mercury and mercury speciation. (From Recommendation M.1. in Volume 1)

Sampling of wells should be expanded to test additional wells to ascertain the spatial distribution of contamination.

Speciation of mercury in well water will identify the volatile component as well as the possible presence of methylmercury.

In-house sampling of mercury levels during showering should be performed in homes with elevated mercury in ground water.

Chapter 10 – INDICATORS OF THE INPUT, ACCUMULATION AND IMPACT OF MERCURY ON NJ ENVIRONMENT

A. Introduction

Environmental indicators are direct or indirect measures of environmental quality that are used to assess the status and trends of environmental conditions (NJDEP 1998a). Indicators provide a cost-effective, repeatable, and socially relevant way for tracking pollutants and the risk associated with exposure. The ultimate human and ecological impact of mercury on NJ's environment, while significant and widespread, tends to occur though relatively subtle and difficult to quantify effects on health, performance, and ecological status. Furthermore, the health and ecological endpoints associated with mercury exposure (e.g., neurologic developmental deficits, decreased reproductive success, eggshell thinning) are also associated with other environmental contaminants (e.g., PCBs). It is therefore difficult to design indicators which directly measure these ultimate impacts. Indicators which are somewhat "upstream" of ultimate impacts, but which are, however, predictive of those impacts are therefore, more useful and more appropriate for evaluating and refining the effect of regulatory and advisory efforts. These "upstream" indicators take the form of measures of mercury environmental flux and exposure.

The Task Force considered a variety of indicators which are predictive of the potential for mercury impacts on health and the environment, and which can document trends in those potentials. These are presented below.

B. Air Deposition of Mercury

The NJ Air Deposition Network has begun collecting data on atmospheric mercury deposition in representative parts of the state. Air deposition is an important contribution to mercury levels in aquatic systems. The network has been designed to collect data in a repeatable manner, which can readily be compared across years. Statistical analysis of mercury deposition data generated by the network should be able to elucidate trends in mercury deposition in various parts of NJ. Such trends can be followed statewide and in various regions of the state to determine whether and to what extent atmospheric mercury deposition decreases from various regional sources and overall. Such decreases can then provide a basis for investigating whether indicators of mercury entry and uptake in aquatic systems are also decreasing in response to decreases in atmospheric source contributions.

C. Mercury Concentration in Surface Water

Mercury concentration in surface water is likely to be an important factor in the entry of mercury into aquatic food chains. Because of the large biomagnification of mercury from water to top level aquatic predators, however, small changes in mercury concentration in surface water can lead to large changes in mercury concentrations in fish. The NJDEP's Ambient Stream Monitoring Network currently monitors mercury in surface water at regular stream sampling locations. The detection limit for mercury in those analyses is 0.1µg/l. In nearly all locations, mercury concentration was below the level of detection. Thus, data from the Ambient Stream Monitoring Network is a useful indicator of significantly elevated mercury in surface water. However, given the magnitude of this detection limit relative to the background levels of mercury in NJ surface waters, such data does not currently provide the basis for a useful indicator of trends in mercury entry and/or mobilization in surface water and availability to aquatic biota. Improved analytical methods are required. Such an indicator would be extremely useful and would permit the linkage of indicators from currently generated atmospheric deposition data and anticipated indicator data on mercury in aquatic systems.

As discussed previously, the USEPA has recently implemented a new surface water criterion for methylmercury based on not exceeding 0.3 ppm methylmercury in top trophic level fish. The translation of this concentration into a corresponding surface water concentration for either total mercury or methylmercury will likely require implementation of sampling and analytical methods with much lower detection limits than that currently employed by the Ambient Stream Monitoring Network. A fish-sampling program is needed to identify waters that exceed the criterion. Data generated in conjunction with the USEPA Surface Water Criterion should be useful in establishing and following trends in a mercury concentration in surface water indicator.

D. Mercury Uptake in the Aquatic Food Chain

Mercury enters the aquatic food chain at the lowest trophic level, starting with the methylation of inorganic mercury by bacteria. Due to the large biomagnification of mercury through the food chain to the top-level predators, changes in mercury at any level in the food chain are predictive of changes throughout the chain. Thus, in theory, an indicator of mercury uptake into the aquatic food chain could be based on measurement of mercury concentration in any easily and reproducible sampled biota. In practice, however, because of this large biomagnification, small changes in mercury concentration at a low trophic level will result in large changes at the top levels. Furthermore, the absolute concentration of mercury at lower trophic levels will be quite small even when levels at upper trophic levels are highly elevated. This makes the development of an indicator based on measurement of mercury in low trophic level biota (e.g., phytoplankton) difficult. An alternative is to develop an indicator based on mercury in upper trophic level biota, which is responsive to short-term changes in mercury uptake. One-year old (young-of-year) fish appear to provide such an indicator (Wiener et al. 1990). While the factors mediating availability and uptake of mercury into the aquatic food chain (e.g., pH, organic carbon content, age of waterbody, etc.) may vary significantly among waterbodies, reproducible sampling of such fish over time within individual waterbodies may provide a reliable basis for the evaluation of trends in mercury uptake into individual aquatic food chains. Viewed in the aggregate, trends in mercury concentration in young-of-year fish for various regions of NJ and statewide, may provide valuable information on how changes in environmental emissions and atmospheric deposition affect aquatic biota.

Trends in mercury levels in NJ fish which are commonly caught and consumed provides the most direct indicator of potential exposure to human and ecological consumers. It is therefore critical that monitoring of this indicator should be carried out on a continuing basis.

Frog tadpoles offer the potential of an indicator species because they are widespread, often abundant, readily studied in the laboratory, and have behaviors that can be quantified. However, simple analysis of whole organisms, would include mercury and other contaminants in the gut, and therefore a period of 48 hours in uncontaminated water is suggested for depuration prior to analysis (Burger and Snodgrass 1998).

E. Mercury Levels in Human Tissue

Mercury, particularly mercury from fish consumption, accumulates in human hair and blood. Sampling of hair and blood in the NJ pregnant population (Stern et al. 2001) as well in other populations elsewhere (USEPA 1997b) have been used to provide a "snapshot" of methylmercury exposure in the population. The design and implementation of a statistically valid and reproducible strategy for sampling mercury levels in hair and/or blood in NJ on a periodic basis could yield estimates of population-based exposure which are comparable from one round of sampling to another. Statistical comparison of these estimates could provide a valid indicator of methylmercury exposure in the NJ population (or in specific subsets of the population such as pregnant women, newborns, adults, etc.). Over time, comparison of multiple rounds of such indicator data would demonstrate trends in methylmercury exposure in the NJ population. Linkage of such trends to trends in mercury levels in commercial fish and/or trends in mercury levels in NJ-specific fish could be investigated.

F. Mercury in Indicator Species

Fish-eating birds such as gulls, terns, herons, and raptors are highly visible and represent top trophic level predators of aquatic and terrestrial ecosystems. Their populations can be monitored, but fluctuations from year to year may obscure long-term trends (Burger et al. 1994). Dramatic population declines of Bald Eagles, Osprey, and Peregrine Falcons, as occurred in the 1940s to 1960's due to DDT, indicated serious contamination (Peakall and Lovett 1972) and were valuable warnings of the widespread impact of persistent pesticides. Many other less conspicuous species were also affected.

Direct measurement of contaminant levels in moribund or dead individuals, may provide information regarding toxicity to the individuals, but is unsuitable as an *indicator* of contaminant burdens. Routine measurement of contaminant levels in unhatched eggs of eagles, ospreys, falcons, hawks, gulls, terns, and herons can provide useful information both on the exposure of the adult birds and on possible impact on hatchability and survival. The data may identify spatial patterns of contamination (Gochfeld 1997) as well as temporal trends (Burger 1993). Eggshell thinning is partly reflective of mercury, but is a more sensitive indicator of organochlorine contamination. Similarly, monitoring of heavy metal levels in feathers of raptors and waterbirds allows documentation of spatial and temporal trends without sacrificing the adult birds---an important consideration particularly for threatened and endangered species (Burger 1993).

Monitoring of reproductive success (nesting attempts, egg laying, hatchability and juvenile survival to fledging, as well as subsequent recruitment of adults to the breeding population) can allow these variables to be used as indicators of environmental quality, but are not specific enough for the monitoring of mercury contamination. However, determining contaminant loads may be important in recovery programs for threatened or endangered species.

In the southern states where humans eat raccoons, this species has proven valuable as a bioindicator for mercury and radionuclides (Gaines et al. 2000). The raccoon offers the advantage of being widespread, conspicuous, and familiar, as well as consuming a wide variety of foods. Although raccoon consumption is not popular in NJ, this widespread animal could also be used as an indicator for ecological impacts.

G. New Technologies for Analysis

The measurement of mercury in environmental media and plant, animal, and human tissues has traditionally been performed by a digestion/extraction procedure followed by cold vapor atomic absorption. A variety of techniques, usually involving gas chromatography, can be used for speciation of organizing mercury (determination of the different mercury species). Detection levels in the ppb range are readily achieved. New techniques have included ultra-clean, mercury free laboratories, and improved detectors, which drive detection levels to the ppt range, although few laboratories have yet acquired these capabilities. These techniques are essential for accurately measuring background levels of mercury in air, water, and lower trophic level biota. Non-destructive analytic techniques are desirable where other studies (molecular, cellular, biochemical) are to be performed on tissues with known mercury concentration. Likewise, techniques that allow the localization of intracellular distribution of mercury exist.

New techniques can also focus on increasing the concentration of mercury in a solution. For example, the use of regenerated cellulose membranes (Babiarz et al. 2000) to concentrate very low levels of methylmercury, are facilitating the determination of mercury in ambient water, reducing detection levels to the sub-nanograms/gram level.

H. Summary and Conclusions: Indicators of the Input, Accumulation and Impact of Mercury on NJ Environment

Indicators provide a critical tool for assessing environmental quality and for evaluating trends in environmental quality especially in conditions of environmental change, such as those which are anticipated to result from reductions in mercury emissions in NJ and the nation. NJ already has in place an elaborate indicator program under its National Environmental Performance Partnerships and Strategic Planning processes.

I. Recommendations

Address critical information gaps concerning the quantities and chemical species of mercury emissions and releases, the fate and transport of mercury in the environment and the exposure pathways. To accomplish this, NJ should:

- **upgrade procedures used in all monitoring programs to include state-of-the-art analytical methods to provide lower detection limits for mercury and mercury speciation. (From Recommendation M.1. in Volume 1).**

Programmatic and analytical investments should be made by the NJDEP to permit the establishment and implementation of indicators of mercury in surface water, mercury in aquatic biota (e.g., young-of-year fish), mercury in human tissue (i.e., hair and blood), and mercury in the eggs or feathers of piscivorous birds nesting in NJ. Such indicators are critical tools for evaluating the status and temporal trends of the impact of mercury on NJ's environment. NJ should invest in state-of-the-art analytic technology.

Develop improved environmental indicators of the impact of mercury on NJ's environment. (From Recommendation "O" in Volume 1).

- **Expand and maintain a statewide ground water monitoring, program for mercury,**
- **Develop and apply indicators of trends of mercury in environemental media, including air deposition, mercury concentrations in surface water, mercury entry into aquatic food chains, mercury levels in fish tissue, mercury levels in human tissue in the NJ population and mercury levels in feathers of piscivorous birds nesting in NJ.**

Research should be continued to evaluate existing environmental indicators of the impact of mercury on NJ's environment. In addition, additional research should be initiated to permit the development and application of those indicators such as mercury uptake in aquatic food chairs which can provide an extremely useful basis for assessing short-term trends in mercury levels and impacts as a means of evaluating the success of mercury reduction efforts.

Chapter 11 - IMPACT OF MERCURY ON TOURISM AND RECREATION IN NJ

A. Introduction

The Task Force was charged to identify the impact of mercury on tourism and recreation in NJ. This is a sizeable task considering the popularity of fishing and the importance of fish as a vector of mercury. Mercury, or any other pollutant, might have a direct impact on a resource by,
1) rendering it unusable, 2) rendering it inaccessible through regulatory restrictions, 3) adherence to advisories reducing fishing or fish consumption, or 4) accurately or inaccurately altering the public's perception of the acceptability of the resource. However, the fact that NJ has taken an aggressive position about issuing fish consumption advisories may also inspire confidence among fishermen and fish consumers.

B. Data and trends in freshwater and marine fishing in NJ

1. Introduction

Freshwater and saltwater fishing are very popular in NJ and contribute substantially to the economy, particularly along the shore. During the past twenty years there have been two countervailing public messages regarding fish consumption emphasizing benefits and risks. The health benefits of fish consumption have generally been emphasized, while issues concerning contaminants in fish have only attracted attention sporadically. There was, however, a great increase in attention to contaminants in fish from November 2000-January 2001 when mercury and related risks from fish consumption were featured on prime time TV news stories.

If people are influenced by such information in deciding whether or not to go fishing, one might expect to see an impact of the information reflected in either an increase or decrease in the number of people fishing in NJ. Several studies cited in the section on Advisories (Vol. II Chapter 9) emphasize that many fisherfolk are unaware of advisories or choose to ignore them. Such data, however, do not identify would-be fishers who chose not to go fishing because of health concerns.

People could react to fish consumption advisories and other information regarding the hazard posed by elevated mercury levels in fish by:

- Remaining unaware
- Being aware but ignoring such information
- Reaching a decision that it is not a problem for them
- Reducing or changing their consumption patterns
- Continuing to fish but catch and release
- Stopping fishing

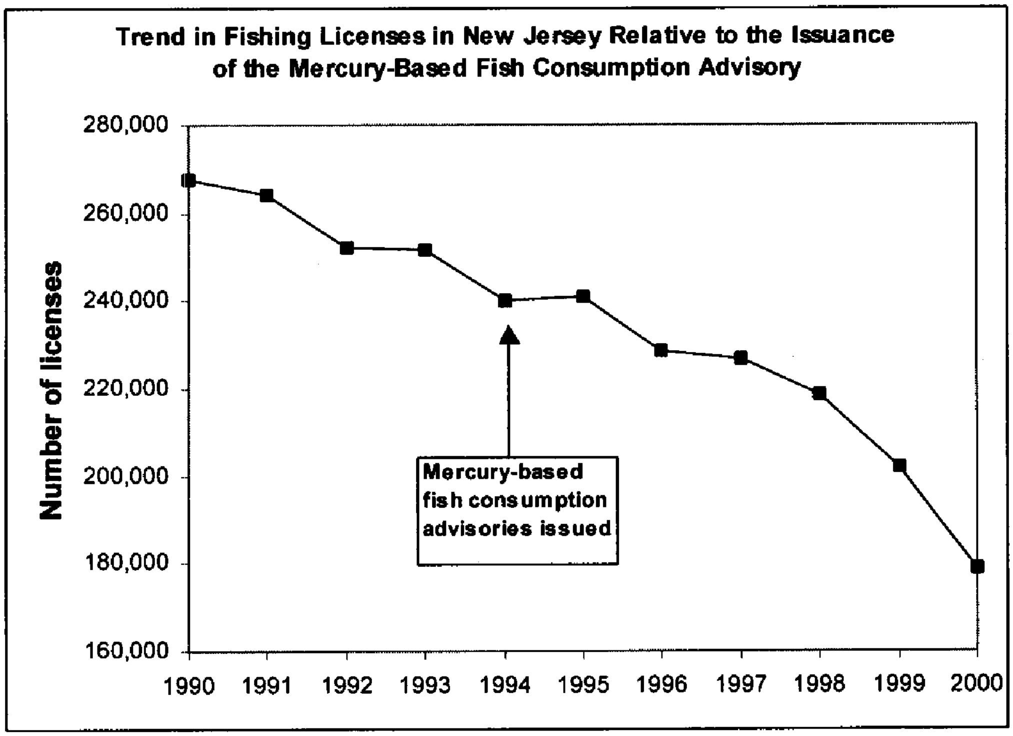
2. *Trends in Fishing Licenses and Fishing Statistics*

a. *Freshwater Licenses*

For those people for whom fishing is a long-term hobby it is not likely that they would stop fishing solely on the basis of advisories or word-of-mouth information. On the other hand, novices might choose other hobbies.

To assess the impact of advisories pertaining to freshwater fish on freshwater fishing, the Task Force obtained information on the issuance of resident fishing licenses (freshwater only) for the period 1990-1997 from the NJDEP Division of Fish and Wildlife. At the beginning of the period there were more than a quarter million licenses issued annually (Figure 2.9), but this number has declined to just over 200,000. The decline was already evident by 1991. The arrow shows the time when advisories were issued in 1994. Although the decline in licenses continued, there is no evidence that it was accelerated by the advisories.

Figure 2.9. Trend in Fishing Licenses in New Jersey Relative to the Issuance of the Mercury-Based Fish Consumption Advisory.



Saltwater fishing contributes about $2 billion annually to the NJ economy, with about 75% coming from recreational fishing. With an estimated 841,000 saltwater anglers, NJ ranks 4th in the nation.

b. *Saltwater Fishing Statistics*

The NJDEP Bureau of Marine Fisheries provided the Task Force data from the National Marine Fisheries Service, which conducts a variety of surveys on coastal fishing activities. The statistics show a big dip in the number of fishers between 1990 and 1992, and then an increase with a peak in 1994, followed by another decline. It is possible that this second decline which coincided approximately with the issuance of the advisories was related to mercury, even though the advisories were specifically for freshwater fish, and not for saltwater fish. The number of person-days fishing did not show any consistent trend and was essentially flat across the period.

c. Official Opinions

The Task Force sought opinions from several officials who would be likely to know of an impact of advisories on fishing. The following offered their opinions:

Gilbert H. Ewing Jr., Chair, NJ Marine Fisheries Council, August 1999,
"The Council is not aware of any documented information regarding the changes in fishermen behavior as a result of concern for mercury pollution."

Robert Soldwedel, NJDEP, Chief, Bureau of Freshwater Fisheries, August 1999.
"It is a fact that there has been a continual downward trend in the sale of fishing licenses in NJ, as well as in most of the other states throughout the country. However, it is extremely doubtful that this decline could be tied into the issue of mercury-based fish consumption advisories. ...."

"Fishermen surveys invariably conclude that very few people are interested in taking fish home to eat. Most of the more dedicated fishermen and those in fishing organizations such as the BASS Federation, Trout Unlimited and Muskies Inc wouldn't even consider keeping a fish regardless of its size, because they recognize that it's in the best interest of their future fishing to release all that they catch. Creel censuses have found catch and release rates as high as 95% for Largemouth Bass and Chain Pickerel. ..."

"It has been our perception that the fish consumption advisories for mercury have little impact."

The above statement regarding catch-and-release refers mainly to fresh water fishing, since interviews of estuarine and coastal fishermen in the Arthur Kill, Raritan Bay, and north Jersey shore, indicated that 61% of 119 people fishing from shore and 94% of those fishing from boats, responded yes to "do you eat fish you catch" (May and Burger 1996).

3. Boat Captain Survey

Although subsistence fishing has been examined extensively, relatively little attention has focused on organized recreational fishing, such as party and charter boats. Yet, in many coastal states, these boats play a major role in recreational fishing, particularly for estuarine and marine fish. For saltwater fish, NJ issues advisories based on PCBs, not on mercury. However, to determine whether the information on mercury toxicity and the advisories might have affected recreational fisheries, a study led by Dr. Joanna Burger of Rutgers University (in collaboration with NJDEP Division of Science, Research and Technology staff) interviewed fishing boat captains on their views (Burger et al., 2001). It must be stressed that this study obtained opinions, and did not try to determine the accuracy of these captains' opinions.

The interviews of NJ party and charter boat captains asked about (1) knowledge about consumption advisories; (2) current and potential communications about advisories to clients; and (3) perception of whether advisories affect fishing. Additional information collected from boat captains during the interviews (frequency and nature of fishing activities, etc.) appears in a separate report (Burger et al., 2001).

From March through May 2000, 93 captains were interviewed by telephone. This was 40% of the 231 registered boat captains in NJ. Another 40% could not be contacted. All but eight of the remainder was willing to participate, but could not arrange a mutually convenient time to be interviewed before their intense fishing season started at the end of May. Of the respondents, 55% were full-time boat captains. The main fish sought were Flounder/Fluke, Bluefish, Striped Bass, Weakfish, and Tuna. Only a small percentage of trips were for Swordfish and Shark, predatory species that are likely to have high mercury levels.

The vast majority (94%) of respondents said they had heard about fish consumption advisories, but their knowledge of these was mixed. Of the 82 captains who said what they had heard about health warnings on fish, 35% mentioned PCBs (13% linked the contaminant to Striped Bass, particularly in the Hudson River. Bluefish also were often mentioned as contaminated with PCBs); 29% mentioned mercury. Several captains erroneously cited particular contaminants or affected species, or mentioned erroneous problems (e.g., lesions on fish) and solutions (e.g., proper preparation or storage removes contamination). Only six captains cited limits on the amount of certain species that one should eat. Surprisingly, about 23% had not heard of the *NJ Fish and Wildlife Digest*, which is the DEP's primary means of conveying information about advisories to anglers.

As for current communications, only 12% of captains said that they currently posted advisories. Some 82% of captains said that customers were aware of advisories, but many fewer thought customers were aware of the actual content of the advisories (e.g., only 20% thought customers were aware of mercury advice). About half said customers had asked about the safety of fish (9% often, 40% sometimes).

The responses captains reported providing to these customers were diverse. Eight of the captains mentioned specific species to avoid, usually Bluefish and Striped Bass. Others mentioned general guidelines (e.g., it "depends on the species," "size of the fish", or the "amount one eats") or categories. Some answers were conflicting, such as (avoid or eat only "bottom feeders"). Nine captains gave advice on how to prepare fish to avoid problems (e.g., "don't eat the dark meat," "always remove the blood line," "filet and skin") which is accurate for dealing with PCBs, but not mercury. Two captains said this is a problem only if one fishes in other than "clean" water, although water column pollution is not the primary source of fish contamination, and many contaminated fish migrate. Some 19% of all boat captains interviewed said there was no problem with fish safety at all. About a third (37%) of the boat captains said they would post consumption warnings if they were provided by the State; another 21% were not sure, with most of the latter saying it would depend on the advisories' content and presentation. Captains who felt public health warnings had affected their business were not less likely to say they would post advisories than other captains.

Boat captains were asked to rate the importance of various factors in the quality of their fishing seasons. Fishing management regulations, the strength of the overall economy, fishing success of clients, and business costs were all cited by 80% or more captains. Competition from commercial fishing boats and the declining size of available fish were cited by over two-thirds. Some 47% of captains cited "public health advice/warnings about saltwater fish contaminants" as a strong or moderate factors in the quality of their fishing season, ranking it seventh (of 13 factors) in importance. Just under a third (31%) felt advisories affected business strongly. About 36% of the captains reported that former customers had decided to stop fishing, but advisories were not reported as among the reasons given.

Captains who took more trips for Bluefish, Fluke, Sea Bass, and Thresher Shark were somewhat more likely to think that advisories affected their business than did those who did not seek these species very often. Bluefish is the only one of these species that is subject to advisories, in this case for PCBs, and this species has a moderately elevated concentration of mercury. There were no differences for those who took trips for Swordfish, Marlin, Stripped Bass, Tuna, or other Shark species, all species with moderate to high mercury values. Captains who felt advisories were affecting their businesses worked closer to areas (e.g., Raritan Bay Complex and New York Harbor) subject to PCB advisories than did other captains, and were more prone to respond that management regulations (e.g., size, limits, seasons) and marketing and advertising by the industry or State were strong influences on the success of their seasons.

C. Summary and Conclusions: Impact of Mercury on Tourism and Recreation in NJ

Many social and economic factors affect the popularity of any recreational activity. The Task Force found no clear evidence that the issuance of fish advisories or the rising public concern about mercury have had a major influence on freshwater or saltwater fishing. Although the number of fishing licenses has declined, the decline did not coincide with the issuance of advisories. Although concerns over PCBs (through saltwater advisories) may have impacted fishing, these advisories were not based on mercury.

About a third of party and charter boat captains, particularly in northern NJ, reported that advisories did hurt their business to a greater or lesser degree. The Boat Captain Survey was not able to evaluate the accuracy of these reports. Reporting that advisories affected business, however, was consistent mainly for those captains who fished for Bluefish, in the waters of the northern part of the state. It is notable that although bluefish have moderately elevated levels of mercury, there is no mercury-based advisory for Bluefish. There are, however, PCB-based advisories for Bluefish in the waters of northern NJ (i.e., the Harbor Estuary). Furthermore, captains who fished for species with more elevated levels of mercury, species which have been highlighted in the press as posing a potential health hazard (i.e., Shark, Tuna), did tend to identify advisories as affecting their business. This survey cannot rule out a small impact from fish consumption advisories in general on the recreational fishing industry in NJ. It seems unlikely that mercury-based advisories in particular have any major impact on the industry. These results indicate that fish advisories may have had a modest impact on the popularity of saltwater fishing in NJ. However, the incomplete information reported by captains suggests that an outreach campaign to boat captains and improved media reporting should provide accurate information, and should include the brochures already published by NJDEP. This campaign may increase the popularity of catch-and-release activities.

D. Recommendations

Advisories should be timely, requiring periodic monitoring of mercury levels in different kinds of fish that are sought by recreational fishers.

Boat captains should be encouraged to post advisories relevant to their fishing activities and should be provided with advisory handouts that present balanced information.

ACRONYMS

μg	microgram
ACGIH	American Conference of Governmental Industrial Hygienists
ASMN	Ambient Stream Monitoring Network
ATSDR	Agency for Toxicology and Disease Registry
AVS	Acid volatile sulfide
BBEP	Barnegat Bay Estuary Program
BSDW	Bureau of Safe Drinking Water
CF	Concentration Factor
CSFII	Continuing Survey of Food Intake by Individuals
CWS	Community Water Systems
DELEP	Delaware Estuary Program
DFW	Division of Fish and Wildlife
DSRT	Division of Science, Research and Technology
ER-M	Effects Range-Medium
GIS	Geographical Information System
GSI	Gonadsomatic Index
HEP	Harbor Estuary Program
HQ	Hazard Quotient
Kg	Kilogram
LOAEL	Lowest-observed-adverse-effect-level
LSI	Liversomatic Index
MCL	Maximum Contaminant Level
MeHg	Methylmercury
MRL	Minimum Risk Level
NAWQA	National Water Quality Assessment
NERP	National Environmental Research Parks
NESCAUM	Northeast States for Coordinated Air Use Management
NEWMOA	Northeast Waste Management Officials' Association
NFTDR	National Fish Tissue Data Repository
ng	Nanogram
NHANES	National Health and Nutrition Examination Survey
NJADN	NJ Atmospheric Deposition Network
NJDEP	NJ Department of Environmental Protection
NJDHSS	NJ Department of Health and Senior Services
NJDOH	NJ Department of Health
NJHDG	NJ Harbor Dischargers Group
NJMSC	NJ Marine Sciences Consortium
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No-observed-adverse-effect-level
NPL	National Priorities List
NRC	National Research Council
NSCRF	National Study of Chemical Residue
ODES	Ocean Data Evaluation System
PCBs	Polychlorinated biphenyls
PLW	Pompton Lakes Works
PMA	Phenyl mercuric acetate
POET	Point-of-entry-treatment

ppb	Part per billion
ppm	Part per million
ppt	Part per trillion
RELMAP	Regional Langranian Model Air Pollution
R-EMAP	Regional Environmental Monitoring & Assessment Project
RfC	Reference Concentration
RfD	Reference Dose
TEAM	Trace Element Analysis Model
TSC	Tissue Screening Concentrations
US E.P.A.	US Environmental Protection Agency
USFDA	US Federal Drug Administration
USFWS	US Fish and Wildlife Service
USGS	United States Geological Survey
WHO	World Health Organization
WQC	Water Quality Criterion
WQS	Water Quality Standard

REFERENCES AND BIBLIOGRAPHY

Abbasi, S.A., and R. Soni (1983) Stress-induced enhancement of reproduction in earthworms, Octochaetus pattoni, exposed to chromium (VI) and mercury (II) - implications in environmental Management. Int. J. Environ. Stud. 22: 43-47.

Academy of Natural Sciences, Philadelphia (ANSP) (1994a) Preliminary assessment of total mercury in fish from lakes, rivers, and reservoirs of NJ. Report to the NJDEPE, Division of Science and Research, Report No. 93-15F, 92 pp.

Academy of Natural Sciences, Philadelphia (ANSP) (1994b) Preliminary assessment of mercury in freshwater fish from Camden County, New Jersey, Rept. No. 94-22D, 21 pp.

Academy of Natural Sciences, Philadelphia (ANSP) (1994c) Total mercury concentrations in fishes from three Hackensack Water Company reservoirs, Rept. No. 94-16F, 28 pp.

Academy of Natural Sciences, Philadelphia (ANSP) (1999) . Phase II 1999 assessment of total mercury concentrations in fishes from rivers, lakes, and reservoirs of New Report to the NJDEP, Division of Science and Research, Report No. 99-.7R, 162 pp.

Adams, D. A., J. S. O'Connor, and S. B. Weisberg (1996) Sediment Quality of the NY-NJ Harbor System. Draft Final Report. USEPA Region 2 and Versar, Inc.

Agocs, M.R., R. Etzel, R. Parrish, D. Paschal, P. Campagna, D. Cohen, E. Kilbourne and J. Heese (1990) Mercury exposure from interior latex paint, New England J. Of Medicine 323:1096-1101.

Anderson, A.C. and Rice, J.C. (1993) Survey of fish and shellfish consumption by residents of the greater New Orleeans area. Bull. Environ. Contam. Toxicol. 51:508-514.

Andren, A. and J.O. Nriagu (1979) The global cycle of mercury. In: The Biogeochemistry of Mercury in the Environment (J.O. Nriagu, Ed.), Elsevier-North Holland, Amsterdam. Pp. 1-21.

Armstrong, F.A.J. (1979) Effects of mercury compounds on fish. Pages 657-670 in J. O. Nriagu (ed.). The biogeochemistry of mercury in the environment. Elsevier/North-Holland Biomedial Press, New York.

Agency for Toxic Substances and Disease Registry (ATSDR) (1993) Toxicological Profile for Lead - Update. US Department of Health and Human Services, Public Health Service, TP-92/12.

Agency for Toxic Substances and Disease Registry (ATSDR) (1999a) Toxicological Profile for Mercury. US Department of Health and Human Services, Public Health Service. March 1999.

Agency for Toxic Substances and Disease Registry (ATSDR) (1999b) Toxicological Profile for Lead. US Department of Health and Human Services, Public Health Service, PB/99/1166704.

Aucott, M. (2000) Personal communication.

Babiart, C.L., S.R. Hoffman, M.M. Shager, J.P. Hurley, A.W. Andren, & D.E. Armstrong (2000). A critical evaluation of tangential-flow ultrafiltration for trace metal studies in freshwater systems, 2. Total mercury and methylmercury, Environ. Science Technol. 34:3428-3434.

Bache C.A., W.H. Gutenmann and D.J. Lisk (1971) Residues of total mercury and methyl mercury in lake trout as a function of age. Science 172:951.

Barr, J.F. (1986) Population dynamics of the Common Loon (*Gavia immer*) associated with mercury-contmainated waters in northwestern Ontario. Occasional Paper No. 56, Canadian Wildlife Service.

Barringer, J.L., C.L. MacLeod, & R.A. Gallagher (1997) Mercury in ground water, soils and sediments of the Kirkwood-Cohansey Aquifer System in the New Jersey Coastal Plain, USGS Open-File Report 95-475, 260 pp.

Barringer, J.L. & C.L. MacLeod (1998) (DRAFT) Relation of mercury to chemical constituents in ground water in the Kirkwood-Cohansey Aquifer System, New Jersey Coastal Plain, and mechanisms for mobilization of mercury from sediments to ground water, Water-Resources Investigations Report 98-DRAFT.

Baumann, J., M.T. Bender and J.M. Williams (2000) Fishing for Trouble: A survey of mercury contamination in America's waterways. Mercury Policy Project and California Communities Against Toxics, and PIRG http://www.pirg.org/reports/enviro/merc.htm

Beijer K, and A. Jernelöv (1979) Methylation of mercury in aquatic environments, pp.203-210 in The Biogeochemistry of Mercury in the Environment (Nriagu JO, ed) Amsterdam: Elsevier/North Holland.

Bemis, J.C., and R.F. Seegal (1999) Polychlorinated biphenyls and methylmercury act synergistically to reduce rat brain dopamine content in vitro. Environ. Health. Perspect. 107:879-885.

Benoit, J.M., W.F. Fitzgerald and A.W.H. Damman (1994) Historical atmospheric mercury deposition in the mid-continental United States as recorded in an ombrotrophic peat bog. In Mercury as a Global Pollutant: Towards Integration and Synthesis. C.J. Watras and J.W. Huckabee, editors. Lewis Press, Boca Raton, FL pp. 187-202.

Benoit, J.M., W.F. Fitzgerald & A.W.H. Damman (1998) A biogeochemistry of an ombrotrophic bog: evaluation of use as an archive of atmospheric mercury deposition. Environmental Research Station, Section A 78, p. 118-133.

Benoit, J.M., Gilmour, C.C. and Mason, R.P. (2001a). Aspects of bioavailability of mercury for methylation in pure cultures of *Desulfobulbus proprionicus (1pr3).* Appl. Environ. Microbiol. 6751-58.

Benoit, J.M., Gilmour, C.C., and Mason, R.P. (2001b). The influence of sulfide on solid-phase mercury bioavailability for methylation by pure cultures of *Desulfobulbus propionicus (1pr3).* Environ Sci Technol. 35:127-132.

Berman M. and R. Bartha (1986a) Levels of chemical versus biological methylation of mercury in sediments. Bull Environ Contam Toxicol 36:401-404.

Berman, M., and R. Bartha (1986b) Control of the methylation process in a mercury-polluted aquatic sediment. Envir. Pollution (Series B) 11: 41-53.

Best, J.B., M. Morita, J. Ragin and J. Best Jr. (1981) Acute toxic responses of the freshwater planarian, Dugesia dorotocephala, to methylmercury. Bull. Environ Contam Toxicol. Jul;27(1):49-54.

Beusterien, K., R. Etzel, M. Agocs, G. Egeland, E. Socie, M. Rouse and B. Mortensen (1991) Indoor air mercury concentrations following application of interior latex paint, Arch. Environ. Contam. Toxicol. 21:62-64.

Beyer, W.N., E. Cromartie, and G.B. Moment (1985) Accumulation of methylmercury in the earthworm, Eisenia foetida, and its effects on regeneration. Bull. Environ. Contam. Toxicol. 35: 157-162.

Bidstrup, L., J.A. Bonnell, D.G. Harvey, and S. Locket (1951) Chronic Mercury Poisoning in Men Repairing Direct Current Meters, Lancet 2:856-861

Biester, H., M. Gosar, S. Covelli (2000) Mercury speciation in sediments affected by dumped mining residues in the drainage area of the Idrija mercury mine, Slovenia, Environ. Sci. & Tech. 34: 3330-3336.

Birge, W.J., J.A. Black, A.G. Westerman, and J.E. Hudson. (1979) The effects of mercury on reproduction of fish and amphibians. In J.O. Nriagu (ed.) The Biogeochemistry of Mercury in the Environment. Elsevier, Amsterdam, The Netherlands, pp. 629-656.

Bloom N.S. (1992) On the chemical form of mercury in edible fish and marine invertebrate tissue. Can J Fish Aquatic Sci 49:1010-1017.

Bodaly, R.A. & R.E. Hecky (1979) Post-impoundment increases in fish mercury levels in the southern Indian Lake Reservoir, Manitoba. Can. Fish. Mar. Serv., Manuscript Rep. 1531, 15 pp.

Bopp, R.F., H.J. Simpson, S.N. Chillrud, D.W. Robinson (1993) Sediment-derived chronologies of persistent contaminants in Jamaica Bay, NY. Estuaries. V. 16. No. 3B: 608-616.

Borg, K., K. Erne, E. Hanko, and H. Wanntorp (1970) Experimental secondary methyl mercury poisoning in the Goshawk (*Accipiter gentilis*) Environ Pollut. 1: 91-104.

Bowerman, W.W. IV, E.D. Evands, J.P. Giesy, and S. Postupalsky (1994) Using feathers to assess risk of mercury and selenium to Bald Eagle reproduction in the Great Lakes region. Arch. Environ. Contam. Toxicol. 27:294-298.

Braune, B.W. and D.E. Gaskin (1987) Mercury levels in Bonaparte's Gull (*Larus philadelphia*) during autumn molt in the Quoddy region, New Brunswick, Canada. Arch. Environ. Contam Toxicol. 16: 539-549.

Brosset, C. and E. Lord (1995) Methylmercury in Ambient Air. Method of Determination and Some Measurement Results. Water, Air, and Soil Pollution 82: 739-750.

Burger, J. (1992) Trace element levels in Pine Snake hatchlings: tissue and temporal differences. Arch. Environ. Contam. Toxicol. 22: 209-213.

Burger, J. (1993) Metals in avian feathers: bioindicators of environmental pollution. Review Environ. Toxicol. 5:203-311.

Burger, J. (1995) Heavy metal and selenium levels in feathers of Herring Gulls (*Larus argentatus*): differences due.

Burger, J. (1997a) Heavy metals in the eggs and muscle of Horseshoe Crabs (*Limulus polyphemus*) from Delaware Bay. Environ. Monitor. Assess. 46: 279-287.

Burger, J. (1997b) Heavy metals and selenium in Herring Gulls (*Larus argentatus*) nesting in colonies from eastern Long Island to Virginia. Environ. Monitor. Assess. 48: 285-296.

Burger, J. (1998) Fishing and risk along the Savannah River: possible intervention, J. Toxicol. Environ. Health 55,405-419.

Burger J., and M. Gochfeld (1985) Comparison of nine heavy metals in salt gland and liver of Greater Scaup (*Aythya marila*), Black Duck (*Anas rubripes*) and Mallard (*A. Platyrhynchos*) Comp. Biochem. Physiol. 81C: 287-292.

Burger, J. and M. Gochfeld (1988) Metals in tern eggs in a New Jersey estuary: a decade of change. Environ. Montor Assess 11: 127-135.

Burger, J. and M. Gochfeld. (1996). Fishing advisories: useful or difficult to interpret? Risk: Health, Safety & Environment 23:23-33.

Burger, J. and M. Gochfeld (1997) Risk, mercury levels, and birds: relating adverse laboratory effects to field biomonitoring. Environ. Research 75: 160-172.

Burger, J., J. Sanchez and M. Gochfeld (1998) Fishing, consumption, and risk perception in fisherfolk along an East Coast Estuary. Environmental Research (A) 77:25-35.

Burger, J. and M. Gochfeld (2001) Effects of chemicals and pollution on seabirds. Pp. 485-526 in Biology of Marine Birds (Schreiber, E.A. and Burger, J. eds) CRC Press, Boca Raton, FL.

Burger, J. and Gochfeld, M. (2001) On developing bioindicators for human and ecological health. Environmental Monitoring and Assessment 66: 23-46.

Burger, J. and J. Snodgrass (1998) Heavy metals in Bullfrog (*Rana catesbeiana*) tadpoles: effects of depuration before analysis. Environ. Toxicol. Chem. 17:2203-2209.

Burger, J., and L. Waishwell (2001) Are we reaching the target audience? Evaludation of a fish fact sheet. Science Total Environ. 277:77-86.

Burger, J., M. Gochfeld, A.A. Rooney, E.F. Orlando, A.R. Woodward and L.J. Guillette, Jr. (2000) Metals and metalloids in tissues of American Alligators in three Florida lakes. Arch. Environ. Contam. Toxicol. 38:501-508.

Burger, J., C.S. Borning, W.L. Stephens, J. Snodgrass, J. and M. Gochfeld (2001a) Mercury and selenium in fish from the Savannah River: species, trophic level, and locational differences. Environ. Research A87:108-118.

Burger, J., K.R. Gaines, and M. Gochfeld (2001b) Ethnic Differences in Risk from Mercury Among Savannah River fishermen. Risk Analysis. In Press.

Burger, J., M. Gochfeld, and C. Leck (1984) Waterbirds on Raritan Bay: a preliminary analysis of their distribution and heavy metal levels. NJ Academy of Sciences.

Burger, J., M. Gochfeld, C.W. Powers, L. Waishwell, C. Warren and B.D. Goldstein, (2001c) Science, policy, stakeholders and fish consumption advisories: developing a fish fact sheet for the Savannah River. Environ. Management 27:501-514.

Burger, J., Pflugh, K.K., Lurig, L., von Hagen L, and Von Hagen S. 1999. Fishing in urban New Jersey: ethnicity affects information sources, perception and complaince. Risk Analysis 19:427-438.

Burger, J., B. Johnson and M. Gochfeld. In press. Perceptions of recreational fishing boat captains: knowledge and effects of fish consumption advisories. Risk Analysis.

Burger, J., R.A. Kennamer, I.L. Brisbin Jr., and M. Gochfeld (1997) Metal levels in Mourning Doves from South Carolina: potential hazards to doves and hunters. Environ Research 75:173-186.

Burger, J., K. Parsons, T. Benson, T. Shukla, D. Rothstein, and M. Gochfeld (1992) Heavy metal and selenium levels in young Cattle Egrets from nesting colonies in the northeastern United States, Puerto Rico, and Egypt. Arch. Environ. Contam. Toxicol. 23: 435-439.

Burger, J., K. Staine, K., and M. Gochfeld. (1993) Fishing in contaminated waters: knowledge and risk perception of hazards by fishermen in New York City. J. Toxicol. Environ. Health 39:95-105.

Burger, J., Sanchez J. & Gochfeld, M. 1998. Fishing, consumption, and risk perception in fisherfolk along an East Coast estuary. Environmental Research 77:25-35.

Burger, J., W. Stephens, C.S. Boring, M. Kuklinski, J.W. Gibbons, and M. Gochfeld (1999) Factors in exposure assessment: ethnic and socioeconomic differences in fishing and consumption of fish caught along the Savannah River, Risk Anal. 19, 421-431.

Callahan, P. and J.S. Weis. (1983) Methylmercury effects on regeneration and ecdysis in fiddler crabs (Uca pugilator, U. pugnax) after short-term and chronic pre-exposure. Arch. Envir. Contam. Tox., 12:707-714.

Carpi, A., Lindberg, S.E., Prestbo, E.M., et al. (1998) Methylmercury contamination and emission to the atmosphere from soil amended with municipal sewage sludge. J. Env. Qual. 26:1650-1655.

Ceccine, G.A., III 1997. Combinations of natural and anthropogenic stressors affect populations of freshwater rotifers. Thesis (Ph.D.) Georgia Institute of Technology. 1997. 137p.

Centers for Disease Control (1996) Mercury exposure among residents of a building formerly used for industrial purposes, NJ 1994. MMWR 45:422-445.

Cernichiari, E., T.Y. Toribara, L. Liang, D.O. Marsh, M.W. Berlin, G.J. Myers, C. Cox, C.F. Shamlaye, O. Choisy, and P. Davidson (1995) The biological monitoring of mercury in the Seychelles study. Neurotoxicology 16:613-628.

Clark, K.E., L.J. Niles (1999) Status and Trends of Contaminant Concentrations in Raptors: Stressor-Condition Indicator Linkages. NJDEP/ESNP. Division of Fish and Game (Unpublished)

Clarkson, T.W., R. Hamada, and L. Amin-Zaki (1984) Mercury. In J.O. Nriagu (ed) Changing metal cycles and human health. Springer-Verlag, Berlin.

Cohen, J.B., J.S. Barclay, A.R. Major, and J.P. Fisher (1999) Wintering Greater Scaup as biomonitors of metal contamination in Federal Wildlife Refuges in the Long Island Sound region. Manuscript.

Cope W.G., J.G. Wiener, and R.G. Rada (1990) Mercury accumulation in Yellow Perch in Wisconsin seepage lakes: relation to lake characteristics. Environ Toxicol Chem 9:931-940.

Costa, H.J. and T.C. Sauer (1994) Distributions of chemical contaminants and acute toxicity in Delaware Estuary sediments. Final Report, DELEP #94-08. For Delaware Estuary Program, US Environmental Protection Agency, by Arthur D. Little, Inc., Cambridge, MA. 89 pp. and appendices.

Cramer, G.M. (1994) Exposure of US consumers to methylmercury from fish. In: DOE/FDA/EPA Workshop on Methylmercury and Human Health. March 22-23, 1994, Bethesda, MD. Biomedical and Environmental Assessment Group, Brookhaven National Laboratory, Upton, NY, Conf-9403156. pp. 103-116.

Cramer, J.S. (ed) (1995) Special Issue: Methylmercury and Human Health. NeuroToxicology 16(4):577-731.

Crump, K.S., T. Kjellstrøm, A.M. Shipp, A. Silvers, and A. Stewart (1998) Influence of Prenatal Mercury Exposure Upon Scholastic and Psychological Test Performance: Benchmark Analysis of New Zealand Cohort. Risk Analysis 18:701-713.

D'Itri, F.M. (1990) The biomethylation and cycling of selected metals and metalloids in aquatic sediments. In: Sediments: Chemistry and Toxicity of In-Place Pollutants. R. Baudo, J. Giesy, and H. Muntau (Eds.) Lewis Publishers, Inc., Ann Arbor. Pp. 164-168.

Davidson, P.W, G.J. Myers, C. Cox (1998) Effects of prenatal and postnatal methylmercury exposure from fish consumption on neurodevelopment. JAMA 280:701-707.

Day (1991) Autopsy report. NJDEP.

De Jesus, I.M., de Oliveira Santos E.C., da Silva Brabo, E., Loureiro,E.C. de Magalhaes Camara, V., Mascarenhas, A.F., da Silva,D.F. and Cleary, D. (2001) Exposure to elemental mercury in urban workers and gold miners from the Tapajos Region, Para, Brazil. Bull. Environ. Contam. Toxicol. 67:317-323.

Delaware Estuary Program. 1996. Comprehensive Conservation and Management Plan.

Dietz, R., F. Riget, and E.W. Born (2000) Geographical differences of zinc, cadmium, mercury and selenium in Polar Bears (Ursus maritimus) from Greenland. Science Total Environ. 245:25-47.

Dooley, J.H. (1992) Natural sources of mercury in the Kirkwood-Cohansey Aquifer System of the New Jersey Coastal Plain, NJGS Report 27, 19 pp.

Draxler, A.F.J., P. Hauge and A.D. Deshpande (1991) Organic contaminants in hepatic tissues of lobster and flounder at the New York Bight "12-Mile" sewage sludge dumpsite : 1987-88 /: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Region, Northeast Fisheries Science Center Woods Hole, Mass.. 10 pp.

Duvall, S.E. and M.G. Barron (2000) A screening level probabilistic risk assessment of mercury in Florida Everglades food webs. Ecotoxicol. Environ. Safety 47:298-305.

Efroymson, R. A., M. Will and G. W. Suter II (1997) Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision. U. S. Dept. of Energy. ES/ER/TM-126/R2.

Egeland, G.M. and J.P. Middaugh (1997) Balancing fish consumption benefits with mercury exposure, Science 278:1904-1905.

Eisenrich, S.J. & J. Reinfelder (2001) Interim Report to the NJDEP, The NJ Atmospheric Deposition Network (NJADN), Dept. of Environmehtal Sciences, Rutgers Univ., New Brunswick, NJ.

Eisler, R. (1987) Mercury Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. US Fish and Wildlife Service Biological Report. 85 (1.10), 90 pp.

Electric Power Research Institute (EPRI) (1994) Mercury Atmospheric Processes: A Synthesis Report; EPRI/TR-104214; Workshop Proceedings.

Elliott, J.E., R.J. Norstrom and G.E.J. Smith. (1996) Patterns, trends, and toxicological significance of chlorinated hydrocarbon and mercury contaminants in Bald Eagle eggs from the Pacific Coast of Canada. Arch. Environ. Contam. Toxicol. 31: 354-367.

EMCON (1998) Remedial Investigation Report, Troy Chemical Corporation, Inc., Newark, New Jersey.

Endo, T., S. Nakaya, R. Kimura and T. Murata (1986) Gastrointestinal absorption of inorganic mercuric compounds in vitro. Toxicol Appl Pharmacol. 83:187-196.

Engstrom, D.R. & E.B. Swain (1997) Recent declines in atmospheric mercury deposition in the Upper Midwest. Environ. Sci. Technol. 31:960-967.

ERM-Southeast, Inc. (1985) Berry's Creek Study, Volume 1, Nature of the Problem. Final Report. Task I of the Berrys Creek RI/FS Investigation.

Exponent Environmental Group (1998) Phase I Remedial Investigation Report: Ventron/Velsicol Site, Wood-Ridge/Carlsdadt, New Jersey (Draft), Volume 1 of 3. Prepared for Velsicol Chemical Corporation and Morton International, Inc.

Exponent Environmental Group and The Academy of Natural Sciences (1999a) Acid Brook Delta Ecological Investigation Phase I Report. Prepared for Du Pont Pompton lakes Works, Pompton Lakes, NJ.

Exponent Environmental Group (1999b) Acid Brook Delta Ecological Investigation, Phase 2 Report. Prepared for Du Pont Pompton Lakes Works, Pompton Lakes, New Jersey.

Faber, R.A., R.W. Risebrough and H.M. Pratt (1972) Organochlorines and mercury in Common Egrets and Great Blue Herons. Environ. Pollution 3:111-122.

Fiedler, N. I. Udasin, M. Gochfeld, G. Buckler, K. Kelly-McNeil, and H. Kipen (1999) Neuropsychological and stress evalaution fo a residential mercury exposure, Environ. Health Perspect. 107: 343-347.

Fields, T.W., T.F. McNevin, R.A. Harkov, & J.V. Hunter (1993) A summary of selected soil constituents and contaminants at background locations in New Jersey, NJDEP- Site Remediation Program and Vision of Science & Research, September, 43 pp.

Fields, T. (1999) Background levels of selected contaminants in New Jersey Soils. Site Remediation Program, NJDEP. Unpublished.

Fimreite, N., Fyfe, R.W. and Keith, J.A. (1970) Mercury contamination of Canadian prairie seed eaters and their avian predators. Canadian Field-Nat. 84:269-276.

Fimreite, N., W.N. Holsworth, J.A. Keith, P.A. Pearce, P.A. and I.M. Gruchy (1971) Mercury in fish and fish-eating birds near sites of industrial contamination in Canada. Canadian Field Nat. 85:211-220.

Fimreite, N. and L. Karstad (1971) Effects of dietary methyl mercury on Red-tailed Hawks. J. Wildlife Management, 35: 293-300.

Finley, M.T. and R.C. Stendell (1978) Survival and reproductive success of black ducks fed methylmercury. Environ. Pollut. 16:51-64.

Fitzgerald, W. F., Mason, R. P., and G.M. Vandal (1991) Atmospheric Cycling and Air-Water Exchange of Mercury over Mid-Continental Lacustrine Regions. Water, Air, and Soil Pollution 56: 745-767.

Fitzgerald, W. (1995) Is mercury increasing in the atmosphere? The need for an atmopheric mercury network (AMNET). Water, Air and Soil Pollution 80: 245-254.

Fitzgerald, W.F., C.H. Lamborg, A.W.H. Damman, J.M. Benoit & P. H. Balcom (1999) Contemporary and historical eolian depositional fluxes of mercury: archival records in ombrotrophic bogs and lake sediments from Nova Scotia and New Zealand. Mercury as a Global Pollutant - 5th International Conference. May 23-28, 1999. Rio de Janeiro, Brazil. Pg. 551.

Fitzgerald, W. F., Mason, R. P., and G.M. Vandal (1991) Atmospheric Cycling and Air-Water Exchange of Mercury over Mid-Continental Lacustrine Regions. Water, Air, and Soil Pollution 56: 745-767.

Frakes, R. A., S. L. Lemieux, and K. E. Clark. (1998) Reproductive success and egg contaminant concentrations of southern New Jersey peregrine falcons. U. S. Fish and Wildlife Service, NJ Field Office, Pleasantville, NJ and NJDEP Division of Fish and Wildlife, Trenton, NJ. 35pp+app.

Friedmann, A.S., M.C. Watzin, J.C. Leiter, and T. Brinck-Johnsen (1996) Effects of environmental mercury on gonadal function in Lake Champlain Northern Pike (*Esox lucius*) Bull. Environ. Contam. Toxicol. 56: 486-492.

Frithsen, J.B., D.E. Strebel, S. Schreiner, and T. Schawitsch (1995) Estimates of contaminant inputs to the Delaware Estuary. For the Delaware Estuary Program, U. S. Environmental Protection Agency, by versar, Incl., Columbia, MD. 162 pp. and appendix.

Gaines, K., C.G. Lord, C.S. Boring, I.L. Brisbin Jr., M. Gochfeld and J. Burger (2000) Raccoons as potential vectors of radionuclide contamiantion to humanf ood chains from a nuclear industrial site, J. Wildlife Managmenet 64:199-208.

Galae-Gorchev, H. (1993) Dietary intake in food and estimated intake of lead, cadmium, and mercury. Food Additives and Contaminants 10:115-128.

Galluzzi, P.F. (1976) Mercury concentrations is Muskrats, *Ondatra zibethiscus*, from the Hackensack Meadowlands, New Jersey, Master□s Thesis, Fairleigh Dickinson Univ., New Jersey.

Galluzzi, P.F. (1981) Mercury concentrations in mammals, reptiles, birds and waterfowl collected in the Hackensack Meadowlands, New Jersey. Presented at: The NJ Acaemy of Sciences, March 28.

Ganther, H.E., C. Goudie, M.L. Sunde, M.J. Kopecky, M.J., P.Wagner, P. S.H. Oh and W.G. Hoekstra (1972) Selenium: relation to decreased toxicity of methylmercury added to diets containing tuna. Science 175:1122-1124.

Ganther, H.E. (1980) Interactions of vitamin E and selenium with mercury and silver. Annals NY Acad Sci. 355:212-226.

Gerrard, P.M. and St Louis, V.L. (2001). The effects of experimental reservoir creation on the bioaccumulation of methylmercury and reproductive success of tree swallows (*Tachycineta bicolor*). Environ Sci Technol. 35:1329-1338.

Gerstenberger S.L., J. Pratt-Shelley, M.S. Beattie and J.A. Dellinger (1993) Mercury concentrations of Walleye (Stizostedion vitreum vitreum) in 34 northern Wisconsin lakes. Bull Environ Contam Toxicol 50:612-617.

Gilman, A.P., G.A. Fox, D.B. Peakall, S.M. Teeple, T.R. Carroll, and G.T. Haynes (1999) Reproductive parameters and egg contaminant levels of the Great Lakes Herring Gulls. J. Wildlife Management 41: 458-468.

Gilmour, C.C. & D.G. Capone (1987) Relationship between Hg methylation and the sulfur cycle in estuarine sediments. Ocean Sciences Abstr. Meet., EOS 68: 1718.

Gilmour, C.C. and G.S. Riedel (2000) A survey of size-specific mercury concentrations in game fish from Maryland fresh and estuarine waters. Arch. Environ. Contam. Toxicol. 39:53-59.

Gnamus, A., Byrne, A.R. and Horvat, M. (2000). Mercury in the soil-plant-deer-predator food chain of a temperate forest in Slovenia. Environ. Science Technol. 34:3337-3345.

Great Lakes Environmental Center (GLEC) (1996) Summary of the Phase I metals sampling and analysis program for the New Jersey component of the NY-NJ Harbor Estuary Program. Traverse City, MI 49686.

Gnamus, A., A.R. Byrne and M. Horvat (2000) Mercury in the soil-plant-deer-predator food chain of a temperate forest in Slovania, Environ. Sci. Technol. 34: 3337-3345.

Gochfeld, M. (1971) Pre-mature feather loss---a "new disease" of Common Terns on Long Island, New York. Kingbird 21:206-211.

Gochfeld, M. (1975) Developmental defects in Common Terns of western Long Island, New York. Auk 92:58-65.

Gochfeld, M. (1980) Tissue distribution of mercury in normal and abnormal young Common Terns. Marine Pollution Bull. 11:362-377.

Gochfeld, M. (1997) Spatial patterns in a bioindicator: heavy metal and selenium concentration in eggs of Herring Gulls (Larus argentatus) in the New York Bight. Arch. Environ. Contam.Toxicol 33:63-70.

Gochfeld, M. and J. Burger (1987a) Factors affecting tissue distribution of heavy metals: age effects and the metal concentration patterns in Common Terns, *Sterna hirundo.* Biol Trace Element Res 12: 389-399.

Gochfeld, M., and J. Burger (1987b) Heavy metal concentrations in the liver of three duck species: influence of species and sex. Environ. Pollution 45:1-15.

Gochfeld, M. and Burger, J. (1998) Temporal trends in metal levels in eggs of the endangered Roseate Tern (Sterna dougallii) in New York. Environ Research. 77A:36-42.

Gochfeld, M., J.L. Baland, T. Shukla, T. Benson, and J. Burger (1996) Heavy metals in Laughing Gulls: gender, age, and tissue differences. Environ. Toxixcol. Chem. 15:2275-2283.

Grandjean, P., P. Weihe, R.F. White, F. Debes, S. Araki, K. Yokoyama, K. Murata, N. Sorensen, R. Dahl and P.J. Jorgensen (1997) Cognitive deficit in 7-year old children with prenatal exposure to methylmercury. Neurotoxicol. Teratol. 19:417-428

Grieb T.M., C.T. Driscoll, S.P. Gloss, C.L. Schofield, G.L. Bowie and D.B. Porcella (1990) Factors affecting mercury accumulation in fish in the upper Michigan Peninsula. Environ Toxicol Chem 9:919-930.

Grier, J.W. (1974) Reproduction, organochlorines, and mercury in northwestern Ontario Bald Eagles. Canadian Field-Nat 88:469-475.

Haines T.A., V.T. Komov and C.H. Jagoe (1992) Lake acidity and mercury content of fish in Darwin National Reserve, Russia. Environ Pollut 78:107-112.

Haines T.A., V.T. Komov, V.E. Matey and C.H. Jagoe (1995) Perch mercury content is related to acidity and color of 26 Russian lakes. Water, Air, Soil Pollution 85:823-828.

Hall, R.A., E.G. Zook and G.M. Meaburn, G.M. (1978) National Marine Fisheries Service Survey of Trace Elements in the Fishery Resource. NOAA Technical Report NMFS SSRF-721. National Marine Fisheries Service, March 1978.

Hamilton, A. (1925) Industrial Poisons in the United States. Macmillan, New York.

Hammond, A.L. (1971) Mercury in the Environment: natural and human factors. Science 171:788-790.

Harada, M. (1995) Minamata Disease: Methylmercury Poisoning in Japan Caused by Environmental Pollution. Crit. Rev. Toxicol. 25:1-24.

Hays, H. and R.W. Risebrough (1971) The early warning of the terns. Natural History.

Hecky R.E., R.A. Bodaly, D.J. Ramsey, and N.E. Strange (1991) Increased methylmercury contamination in fish in newly formed freshwater reservoirs, pp. TO GET ORIGINAL. in Advances in Mercury Toxicology. (Clarkson TFW, Suzuki T, Imura A, eds) New York: Plenum.

Hochreiter, J.J., Jr. and J. Kozinski (1985) Quality of water and bed material in streams of Logan Township, Gloucester County, New Jersey, 1984. US Geological Survey Water Resources Investigations Report 85-4300.

Hoffman, R.D. and R.D. Curnow (1973) Toxic heavy metals in Lake Erie Herons. Proc. Conf. Great Lakes Research 16:50-53..

Huckabee J.W., J.W. Elwood and S.G. Hilderbrand (1979) Accumulation of mercury in freshwater biota pp. 277-301 et al. in The Biogeochemistry of Mercury in the Environment (Nriagu J.O., ed) Amsterdam: Elsevier/North Holland.

Hughes, K.D., P.J. Ewins and K.E. Clark (1997) A comparison of mercury levels in feathers and eggs of Osprey (Pandion haliaetus) in the North American Great Lakes. Arch. Environ. Contam. Toxicol. 33:441-452.

Hunter, D. (1974) The Diseases of Occupations. English Universities Press, Ltd, London.

Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese, and W. Basham (1997) Environmental Contaminants Encyclopedia, Mercury Entry, National Park Service, Water Resources Division, Fort Collins, Colorado.

Jackson, T.A. (1991) Biological and environmental control of mercury accumulation by fish in lakes and reservoirs of northern Manitoba, Canada. Can J Fish Aquatic Sci 48:2449-2470

Jacobs, H.L., H.D. Kahn, K.A. Stralka and D.B. Phan (1998) Estimates of per capita fish consumption in the US based on the Continuing Survey of Food Intake by Individuals (CSFII) Risk Analysis 18:283-291.

Jacobson, J.L. and S.W. Jacobson (1996) Intellectual impairment in children exposed to polychlorinated biphenyls in utero. New Engl. J. Med 335:783-789.

Jagoe C.H., P.L. Shaw-Allen, and B.S. Gill (1996) Na+-K+-ATPase activity in largemouth bass (Micropterus salmoides) from three reservoirs with different levels of mercury contamination. Aquatic Toxico. 36:161-176.

Johnston T.A., R.A. Bodaly and J.A. Mathias (1991) Predicting fish mercury levels from physical characteristics of boreal reservoirs. Can J Fish Aquatic Sci 48:1468-1475.

Jurczk, N.U. (1993) An ecological risk assessment of the impact of mercury ocntamiantion in the Florida Everglades. Master□s Thesis, Univ. Of Florida, Gainesville, FL.

Kabata-Pendias, A. and H. Pendias (1984) Trace Elements in Soils and Plants. CRC Press, Boca Raton FL.

Khan, B. and B. Tansel (2000) Mercury bioconcentrations factors in American Alligators (Alligator mississippiensis) in the Florida Everglades. Ecotoxicol. Environ. Safety 47:54-58.

Khan, A.T., and J.S. Weis. (1987) Effects of methylmercury on sperm and egg viability of two populations of killifish (Fundulus heteroclitus) Arch. Envir. Contam. Tox., 16:499-505.

Khan, A.T. and J.S. Weis (1993) Bioaccumulation of four heavy metals in two populations of mummichog, (*Fundulus heteroclitus*) Bull. Enviorn. Contam. Toxicol. 51:1-5.

Kinjo, Y., H. Higashi, A. Nakano, M. Sakamoto and R. Sakai (1993) Profile of Subjective Complaints and Activities of Daily Living Among Current Patients with Minamata Disease After 3 Decades. Environ. Res. 63-241-251.

Kjellstrøm, T., P. Kennedy, S. Wallis and C. Mantell (1986) Physical and Mental Development of Children with Prenatal Exposure Mercury from Fish. Stage 1: Preliminary Tests at Age 4. National Swedish Environmental Protection Board, Report 3080, Solna, Sweden.

Kjellstrøm, T., P. Kennedy, S. Wallis, A. Stewart, B. Lind, T. Wutherspoon and C. Mantell (1989) Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish. Stage 2: Interviews and Psychological Tests at Age 6. National Swedish Environmental Protection Board, Report 3642, Solna, Sweden.

Komsta-Szumska, E., K.R. Reuhl and D.R. Miller (1983) Effect of selenium on distribution, demethylation, and excretion of methylmercury by the guinea pig. J. Toxicol. Environ. Health.1:775-785.

Kosatsky, T. and P. Foran (1996) Do Historic Studies of Fish Consumers Support the Widely Accepted LOEL for Methylmercury in Adults. Neuro Toxicol. 17: 177-186.

Krabbenhoft, D.P. (1999) Summary Document for the USGS Workshop on Mercury Cycling in the Environment. Golden, CO, July 7-9, 1996. Website: http://toxics.usgs.gov/toxics/pubs/hg/summary.shtml.

Kurland, L.T., S.N. Faro and H. Siedler (1960) Minamata Disease. World. Neurology 1: 370-395.

Lacerda, L.D., E.D. Bidone, A.F. Guimaraes and W.C. Pfeiffer (1994) Mercury concentrations in fish from the Itacaiunas-Parauapebas River system, Carajas region, Amazon. An Acad Bras Cienc. 66:373-9.

Lambertini, M. (1982) Mercury levels in Larus audouinii and Larus michahellis breeding in Capraia Island (Tyrrhenian Sea) Rev. Ital. Ornit. 52:75-79.

Lange T, D. Richard, and H. Royals (2000) Long-term trends of mercury bioaccumulation in Florida's Largemouth Bass, Annual Meeting South Florida Mercury Science Program, Tarpon Springs FL.

Latif, M.A., R.A. Bodaly, T.A. Johnston and R.J. Fudge (2001) Effects of environmental and maternally derived methylmercury on the embryonic and larval stages of walleye (Stizostedion vitreum) Environ Pollut. 111:139-148.

Lawrence, A.L. and R.P. Mason (2001) Factors controlling the bioaccumulation of mercury and methylmercury by the estuarine amphipod Leptocheirus plumulosus. Environ Pollut. 111:217-231.

Lebel, J., D. Mergler, M. Lucotte, M. Amorim, J. Dolbec, D. Miranda, G. Arantès, I. Rheault and P. Pichet (1996) Evidence of Early Nervous System Dysfunction in Amazonian Populations Exposed to Low-Levels of Methylmercury. Neuro Toxicol. 17:157-168.

Lebel, J., D. Mergler, F. Branches, M. Lucotte, M. Amorim, F. Larribe and J. Dolbert (1998) Neurotoxic Effects of Low-level Methylmercury Contamination in the Amazonian Basin. Environ. Res. 79:20-32.

Leggett, R.W., N.B. Munro and K.F. Eckerman (2001) Proposed revision of the ICRP model for inhaled mercury vapor. Health Physics 81:450-455.

Lewis, S.A. and R.W. Furness (1991) Mercurya ccumulation and excretion by laboratory-reared black-headed gull *Larus ridibundus* chicks, Arch. Environ. Contam. Toxicol. 21: 316-320.

Lindberg, P. (1984) Mercury in feathers of Swedish Gyrfalcons, Falco rusticolus in relation to diet. Bul. Environ. Contam. Toxicol. 32:453-459.

Lindberg, P. and T. Odsjö (1983) Mercury levels in feathers of Peregrine Falcon Falco peregrinus compared with total mercury content in some of its prey species in Sweden. Environ. Pollut. 5: 297-318.

Lipsky, D., R.J. Reed, and R. Harkov (1980) Mercury Levels in Berry's Creek. Office of Cancer and Toxic Substances Research. NJDEP. 76 pp.

Lockhart, W.L., J.F. Uthe, A.R. Kenney and P.M. Mehrle (1972) Methylmercury in Northern Pike (*Esox lucius*): distribution, elimination and some biochemical characteristics of contaminated fish. J. Fish. Res. Board Can., 29: 1519-1523.

Lockhart, W.L., R.W. Macdonald, P.M. Outridge, P. Wilkinson, J.B. Delarond, & J.W.M. Rudd (1999) Tests of the fidelity of lake sediment core records of mercury deposition to known historics of mercury contamination. Mercury as a Global Pollutant - 5th International conference. May 23-28, Rio de Janeiro, Brazil.

Lofroth, G. (1970) Methyl Mercury: A review of the health hazards and side effects associated with the emission of mercury compounds into natural systems. Ecological Research Committee Bulletin No. 4, (2nd ed.) Swedish Natural Science Research Council, Stockholm, Sweden.

Malm, O., F.J. Branches, H. Akagi, M.B. Castro, W.C. Pfeiffer, M. Harada, W.R. Bastos and H. Kato (1995) Mercury and methylmercury in fish and human hair from the Tapajos River basin, Brazil. Science Total Environ. 175:141-150.

Marien, K. and G.M. Patrick (2001) Exposure analysis of five fish-consuming populations for overexposure to methylmercury. J. Exposure Anal. Environ. Epidemiol. 11:193-206.

Marsh, DO., M.D. Turner, J.C. Smith, P. Allen and N. Richdale (1995) Fetal methylmercury study in a Peruvian fish-eating population. Neurotoxicology 16:717-726.

Martin-Doimeadios, R.C., Wasserman, J.C., Bermejo, L.F., Amouroux, D., Nevado ,J.J., and Donard, O.F. (2000) Chemical availability of mercury in stream sediments from the Almaden area, Spain. J Environ Monit.2:360-366.

Mason, R.P., W.F. Fitzgerald and F.M.M. Morel (1994) The biogeochemical cycling of elemental mercury: anthropogenic influences. Geochim. Cosmochim. Acta 58/15: 3191-3198.

Matsunaga, T., T. Ueno, R.L.R. Chandradjith, H. Amano, M. Okunura & H. Hashitani (1999) Cesium-137 and mercury contamination in lake sediments. Chemosphere. 39 (2): 269-283.

May, H. And J. Burger (1996) Fishing in a poluted estuary: fishing behavior, fish consumption and potential risk, Risk Analysis 16:459-471.

McFarlane G.A. and W.G. Franzin (1980) An examination of Cd, Cu, and Hg concentrations in livers of northern pike Esox lucius, and white sucker, Catastomus commersoni, from five lakes near a base metal smelter at Flin Flon, Manitoba. Can J Fish Aquatic Sci 37:1573-1578.

McKim, J.M., G.F. Olson, G.W. Holcombe, and E.P. Hunt (1976) Long-term effects of methylmercuric chloride on three generations of brook trout (Salvelinus fontinalis): Toxicity, accumulation, distribution, and elimination. J. Fish. Res. Board Can. 33: 2726-2739.

McLaughlin, M. and R. Hamon (2001). Perspectives on inputs of cadmium to the food chain, pp. 60-65, in Syers, K and M. Gochfeld (eds). Environmental Cadmium in the Food Chain: Sources, Pathways, and Risks. Proceedings of SCOPE Workshop, Belgian Academy of Sciences, September 2000.

Meili, M. (1995) Pre-industrial atmospheric deposition of mercury: uncertain rates from lake sediment and peat cores. 1995. Water, Air, and Soil Pollution 80 (104): p. 637-640.

Miller D.R. and H. Akagi (1979) pH affects mercury distribution, not methylation. Ecotoxicol Environ Safety 3:36-38.

Minnesota Pollution Control Agency (1998) Options and Strategies for Reducing Mercury Releases, Source Reduction Feasibility and Reduction Strategies Committee Report, Minnesota Pollution Control Agency, Policy and Planning Division, Majors Air Unit, 520 Lafayette Rd., St. Paul, MN.

Monmouth County (NJ) Board of Health (1989) Interim report on the nine coastal lakes in Monmouth County.

Murphy, E.A., & M. Aucott (1999) A methodology to assess the amounts of pesticidal mercury used historically in New Jersey, Journal of Soil Contamination 8(1): 131-148.

Murphy, E.A., J. Dooley, H.L. Windom and R.G. Smith Jr. (1994) Mercury species in potable groundwater in southern New Jersey. Water, Air, and Soil Pollution 78: 61-72.

National Atmospheric Deposition Program (NADP) (2000) 1999 Annual Summary, NADP Data Report 2000-02, NADP Program Office, Illinois State Water Survey, Champaign, IL.

National Center for Health Statistics (NCHS) (2001) National Health and Nutrition Examination Survey (NHANES IV), U.S. Public Health Service, Hyattsville, Maryland.

National Center for Health Statistics (NCHS) (1978) National Health and Nutrition Examination Survey (NHANES I), Selected Findings: Food consumption profiles of white and black persons 1-74 years of age in the U.S., 1971-74, Pata 21:1-11.

National Institute of Environmental Health Sciences (NIEHS) (1998) Report on the Workshop on Scientific issues relevant to assessment of health effects from exposure to methylmercury, Brownestone Hotel, Raleigh, NC, Nov. 18-20.

National Research Council (NRC) (2000) Toxicological Effects of Methylmercury. National Academy Press, Washington, D.C.

National Oceanic and Atmospheric Administration (NOAA) (1998) Raw data file. NOAA National Status and Trends Program.

National Oceanic and Atmospheric Administration (NOAA) (1999) Data Base for Newark Bay. Prepared by Hazardous Materials Response and Assessment Division.

National Wildlife Federation (1999) Clean the Rain, Clean the Lakes: Mercury in Rain is Polluting the Great Lakes. National Wildlife Federation Ann Arbor, MI, http://www.nwf.org/greatlakes

National Institute of Environmental Health Sciences (NIEHS) (1998) Scientific Issues Relevant to Assessment of Health Effects from Exposure to Methylmercury. Report of the November 18-20, 1998 Workshop, Raleigh, NC.

NESCAUM, NEWMOA, NEIWPCC and EMAN (1998) Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action. Northeast States for Coordinated Air Use Management, Boston, MA.

New Jersey Department of Environmental Protection and Energy (NJDEPE) (1993) Task Force on Mercury Emissions Standard Setting. Final Report on Municipal Solid Waste Incineration. Vol. II: Environmental and Health Issues. July 1993.

New Jersey Department of Environmental Protection (NJDEP) (1995a) A guide to health advisories for eating fish and crabs caught in NJ waters, 4 pp, Division of Science, Research and Technology, Trenton, NJ, 4 pp.

New Jersey Department of Environmental Protection (NJDEP) (1995b) NJ household fish consumption study, Conducted by the Center for Public Interest Poling, Eagleton Institute of Politics, Rutgers Univ. And the NJ Marine Sciences Consortium. Final Report, Trenton, NJ.

New Jersey Department of Environmental Protection (NJDEP) (1998a) Environmental Indicators Technical Report, National Environmental Performance Partnership System (NEPPS).

New Jersey Department of Environmental Protection (NJDEP) (1998b) Guidance for Sediment Quality Evaluations. Site Remediation Program, NJDEP, 28 pp.

New Jersey Department of Environmental Protection (NJDEP) (1996) The Delaware Estuary Program, Comprehensive Conservation and Management Plan. USEPA Region III. Philadelphia, PA. Versar, Inc. 1994. Estimates of contaminant inputs to the Delaware River from nonpoint sources. Contract draft report to the Delaware Estuary Program.

New Jersey Department of Environmental Protection (NJDEP) (1999) Toxics Source Reduction Plan for the NY-NJ Harbor Estuary. Office of Program Coordination. New York-New Jersey Harbor Estuary Program Including the Bight Restoration Plan. 1996. Final Comprehensive Conservation and Management Plan. US Environmental Protection Agency.

New Jersey Department of Environmental Protection (NJDEP), Div. Fish and Wildlife (2000) New Jersey fish and wildlife digest. Vol.13-.2: 24-25pp.

New Jersey Department of Health and Senior Services (NJDHSS) and NJDEP (1997) A guide to eating fish and seafood; what you should know if you are: pregnant, planing to be pregnant or have a young child, Trenton, NJ, 7 pp.

New York State Department of Environmental Conservation (NYSDEC) (1981) Autopsy report on American Kestrel. Unpublished document.

New York-New Jersey Harbor Estuary Program including the New York Bight Restoration Plan (1996) Comprehensive Conservation and Management Plan. USEPA Region II, New York, NY.

Newland, M.C. and E.M. Paletz (2000) Animal studies of methylmercury and PCBs: what do they tell us about expected effects in humans. NeuroToxicology 21:1003-1028.

Newland, M.C. and E.B. Rasmussen (2000) Aging unmasks adverse effects of gestational exposure to methylmercury in rats. Neurotoxicol Teratol. 22:819-28.

Nichols J, S. Bradbury and J. Swartout (1999) Derivation of wildlife values for mercury. J Toxicol Environ Health B Crit Rev. 2:325-355.

Nierenberg, D.W., R.E. Nordgren, M.B. Chang, R.W. Siegler, M.B. Blayney, F. Hochberg, T.Y. Toribara, E. Cernichiari and T. Clarkson (1998) Delayed cerebellar disease and death after accidental exposure to dimethylmercury. New Engl. J. Med. 338: 1672-1676.

Niimi, A.J., and G.P. Kissoon (1994) Evaluation of the critical body burden concept based on inorganic and organic mercury toxicity to Rainbow Trout (*Oncorhynchus mykiss*) Arch. Environ. Contam. Toxicol. 26: 169-178.

Niimi, A.J. and L. Lowe-Jinde (1984) Differential blood cell r atios of Rainbow *Trout (Aslmo gairdneri)* exposed to methylmercury and chlrobenzenes, /arcg, /ebvuirb, /cibtan, /tixucik, 13L 393-311.

Nriagu, J.O. (1979) The biogeochemistry of mercury in the environment/editor, J.O. Nriagu. Publication info: Amsterdam, New York, Elsevier/North-Holland Biomedical Press.

Nriagu, J.O. (1989) A global assessment of natural sources of atmospheric trace metals. Nature 338:47-49

Odsjö, T. 1975. Toxic chemicals in sedentary and migratory birds in Fennoscandia and the Baltic area. Ornis Fenn. 52:74-82.

Olsen, S.F., J. Olsen and Frische, G. (1990) Does fish consumption during pregnancy increase fetal growth? Internatl J. Epidemiology 19: 971-977.

Orloff, K.G., G. Ulirsch, L. Wildes, A. Block, J. Fagliano, & J. Pasqualo Jr. (1997) Human exposure to elemental mercury in a contaminated residential building, Arch. Environ. Health 52:169-172.

Pai, P., P. Karamachandani and C. Seigneur (1997) Simulation of the Regional Atmospheric Transport and Fate of Mercury Using a Comprehensive Eulerian Model. Atmospheric Environment 31: 2707-2732.

Park J-G and L.R. Curtis (1997) Mercury distribution in sediments and bioaccumulation by fish in two Oregon Reservoirs: point-source and nonpoint-source impacted systems.

Peakall, D.B. and R.J. Lovett. (1972) Mercury: its occurrence and effects in the ecosystem. BioScience 22(1):20-25.

Perry, D. M., J. S. Weis and P. Weis (1988) Cytogenetic effects of methylmercury on embryos of the killifish, Fundulus heteroclitus. Arch. Envir. Contam. Tox., 17:569-574.

Pfeiffer, W.C., L.D. de Lacerda, O. Malm, C.M. Souza, E.G. da Silveira and W.R. Bastos (1989) Mercury concentrations in inland waters of gold mining areas in Rondonia, Brazil. Science Total Environ. 87-88:233-240.

Pflugh, K.K., L. Lurig, L.A. von Hagen, S. Von Hagen and J. Burger (1999) Urban anglers' perception of risk from contaminated fish, Sci. Tot. Environ. 228:203-218.

Pillay, K.K.S., C.C. Thomas Jr., J.A. Sondel and C.M. Hyche CM (1972) Mercury pollution of Lake Erie ecosphere, Environ. Res. 5:172-181.

Prestbo, E.M. and N.S. Bloom (1994) Mercury Speciation Adsorption (MESA) Method Intercomparison Results in Combustion Flue Gas. In: Proceedings of the Eleventh Annual International Pittsburgh Coal Conference: Coal-Energy and the Environment, Volume 1. The University of Pittsburgh School of Engineering Center for Energy Research, September 12-16, 1994, pp. 557-562.

Price, P.S; Su, S.H, Gray, M.N. (1994) The effect of sampling bias on estimates of angler consumption rates in creel surveys. J. Exposure Anal. Environ. Epidemiol. 4:355-372.

PTI (1997) Alternative Risk-Based Residential Cleanup Level for Mercury in Hawthorne Site Soil. Vol. 1 - Technical Report. Prepared for Merck & Co. Inc., Somerset, NJ. PTI Environmental Services, Bellevue, WA., March 1997.

Ramazzini, B. 1713. De Morbis Artificum Diatriba. Translation by W.C. Wright. Univ. Chicago Press, Chicago.

Ramprashad, F. and K. Ronald. (1977) A surface preparation study on the effect of methylmercury on the sensory hair cell population in the cochlea of the Harp Seal (Pagophilus groenlandicus Erxleben, 1977) Canad. J. Zool. 55: 223-230.

Rappe, A. (1973) Influence de la pollution par le mercure sur les populations d'oiseaux. L'Oiseau et R.F.O. 43: 196-204.

Redmayne, A.C., Kim, J.P., Closs, G.P. and Hunter, K.A. (2000) Methyl mercury bioaccumulation in Long-finned Eels *Anguilla dieffenbachia,* from three rivers in Otago, New Zealand. Sci. Total Environ. 262:37-47.

Reid, R.N., J.E. O'Reilly & V.S. Zdanowicz (1982) Contaminants in New York Bight and Long Island Sound sediments and demersal species, and contaminant effects on benthos, summer 1980: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Mass., 96 pp.

Ribeyre, F. and A. Bouduo (1994) Experimental study of inorganic and methylmercury bioaccumulation by four species of freshwater rooted macrophytes from water and sediment contamination sources. Ecotoxicol Environ Saf. 28:270-286.

Rice, D.C. (1995) Neurotoxicity of lead, methylmercury, and PCB's in relation to the Great Lakes, Environmehtal Health Persepctive 103(supplement 9): 71-81.

Rice, D.C. (2000) Identification of functional domains affected by developmental exposure to methylmercury: Faroe Islands and related studies, Neuro. Toxicol. 21:1039-1044.

Riley, D.M., C.A. Newlov, T.O. Leal-Almerz & V.M. Thomas (2001) Assessing elemental mercury vapor exposure from cultural and religious practices, Environ. Health Perspect. 109:779-784.

Rissanen T., S. Voutilainen, K. Nyyssonen, T.A. Lakka and J. Salonen (2000) Fish oil-derived fatty acids, docosahexaenoic acid and docosapentaenoic acid , and the risk of acute coronary events: the Kuopio ischaemic heard disease risk factor study. Circulation 102:2677-2679.

Roberts, M. R. and K. E. Clark. (1995) Evaluation of contaminant residues in Delaware Bay bald eagle nestlings. Report by USFWS, NJ Field Office (Pleasantville) and NJDEP, Division of Fish, Game and Wildlife (Tuckahoe).

Rompala, J.M., F.W. Rutosky, and D.J. Putnam (1984) Concentrations of environmehtal contaminants from selected waters in Pennsylvania. US Fish and Wildlife Services Report, State College, PA.

Ronald, K, S.V. Tessaro, J.F. Uthe, H.C. Freeman, and R. Frank. (1977) Methylmercury poisoning in the Harp Seal (Pagophilus groenlandicus) Sci. Total Environ. 8: 1-11.

Rupp, E.M., Miller, F.L., and Baes, C.F. (1980) Some results of recent surveys of fish and shellfish consumption by age and region of U.S, residents. Health Physics 39:169-175.

Salonen J.T, Seppanen K, Nyyssonen K, Korpela H, Kauhanen J, Kantola M, Tuomilehto J, Esterbauer H, Tatzber F, and Salonen R (1995) Intake of mercury from fish, lipid peroxidation, and the risk of myocardial infarction and coronary cardiovascular, and any death in eastern Finnish men. Circulation 1; 9: 645-55.

Santoro, E.D., and S.J. Koepp (1986) Mercury levels in organisms in proximity to an old chemical site (Berrys Creek, Hackensack Meadowlands, New Jersey, USA) Mar. Poll. Bull. 17(5): 219-224.

Schantz, S.L. (1996) Developmental neurotoxicity of PCBs in humans: what do we know and where do we go from here. Neurotox and Teratol. 18217-227, 1996.

Scheuhammer, A.M. 1991. Effects of acidification on the availability of toxic metals and calcium to wild birds and mammals. Environ. Pollut. 71: 329-375.

Schuler, C.A., R.G. Anthony and H.M. Ohlendorf (1990) Selenium in wetlands and waterfowl foods at Kesterson Reservoir, California, 1984. Arch. Environ. Contam. Toxicol. 19:854-853.

Seigneur, C., K. Lohman, P. Pai, K. Heim, D. Mitchell and L. Levin (1999) Uncertainty Analysis of Regional Mercury Exposure. Water, Air and Soil Pollution 112:151-162.

Shephard, B.K. (1998) Quantification of ecological risks to aquatic biota from bioaccumulated chemicals. Pp. 2-31 to 2-52, IN: National Sediment Bioaccumulation Conference Proceedings. September 11-13, 1996, Bethesda, Maryland. USEPA 823-R-98-002, Office of Water.

Simon, O. and A. Boudou (2001a) Direct and Trophic Contamination of the Herbivorous Carp Ctenopharyngodon idella by Inorganic Mercury and Methylmercury. Ecotoxicol Environ Safety. 50:48-59.

Simon, O. and A. Boudou (2001b) Simultaneous experimental study of direct and direct plus trophic contamination of the crayfish Astacus astacus by inorganic mercury and methylmercury. Environ Toxicol Chem. 20:1206-1215.

Sites, A. (1994) Removing mercury using POET systems. Water Conditioning and Purification, October 1994: 94-99.

Sjoblom, A., Meili, M., and Sundbom, M. (2000) The influence of humic substances on the speciation and bioavailability of dissolved mercury and methylmercury, measured as uptake by Chaoborus larvae and loss by volatilization. Science Total Environ. 261:115-124.

Smith, J.C., P.V. Allen and R. Von Burg (1997) Hair methylmercury levels in US women, Arch. Env. Health 52:476-580.

Smith, H.M. and E.D. Brodie, Jr. (1982) A Guide to Field Identification, Reptiles of North America. Golden Press, New York, 240 pages.

Smith, G.M., A.T. Khan, J.S. Weis and P. Weis. (1995) Behavior and brain chemistry correlates in nummichogs (*Fundulus heteroclitus*) from polluted and unpolluted environments. Mar. Environ. Res. 39: 329-333.

Smith, G.M., and J.S. Weis (1997) Predator-prey relationships in mummichogs (Fundulus heteroclitus (L.): effects of living in a polluted environment. J Exper Marine Biol Ecol. 209:75-87.

Snarski, V.M. and G.F. Olson. (1982) Chronic toxicity and bioaccumulation of mercuric chloride in the Fathead Minnow (Pimephales promelas) Aquat. Toxicol. 2: 143-156.

Snodgrass, J.W., Jagoe, C.H., Bryan, L., Brant, H.A. and Burger, J. (2000) Effects of trophic status and wetland morphology, hydroperiod and water chemistry on mercury concentration in fish. Canad. J. Fisher. Aquatic Sci. 57:171-180.

Snyder, N.F.R., Snyder, H.A., Lincer, J.L. and Reynolds, R.T. (1973) Organochlorines, heavy metals, and the biology of North American Accipiters. BioScience, 23: 300-305.

Solonen, T. And M. Lodenius (1990) Feathers of birds of prey as indicators of mercury contamination in southern Finalnd, Holarct Ecol. 13: 229-237.

Solonin and Lodenius. (1984)

Southworth, G.R., M.J. Peterson and M.G. Ryon (2000) Long-term increased bioaccumulation of mercury in Largemouth Bass follows reduction of waterborne selenium, Chemosphere 41:1101-1105.

Spalding, M.G., P.C. Frederick, H.C. McGill, S.N. Bouton and L.R. McDowell (2000a) Methylmercury accumulation in tissues and its effects on growth and appetite in captive Great Egrets, J. Wildlife Diseases 36:411-422.

Spalding, M.G., P.C. Frederick, H.C. McGill, S.N. Bouton, L.J. Richey, I.M. Schumacher, C.G.M. Blackmore and J. Harrison (2000b) Histologic, neurologic, and immunologic effects of methylmercury in captive Great Egrets, J. Wildlife Diseases 36:423-435.

Spronk, N. and G.C. Hartog. (1970) Mercury in birds of prey. Ardea 59:34-37.

Spry, D.J. and J.G. Wiener (1991) Metal bioavailability and toxicity to fish in low-alkalinity lakes: a critical review, Environ. Pollut. 71: 243-304.

Steidl, R. J., C. R. Griffin, and L. J. Niles. (1991) Contaminant levels in osprey eggs and prey reflect regional differences in reproductive success. J. Wildl. Manage. 55(4): 601-608.

Stern, A.H., (1997a) A Review of Merck Submission on Bioavailability of Mercury Contamination at Hawthorne Site " NJDEP Memo from Alan Stern to Barry Frasco, July 28.

Stern, A.H. (1997b) An Estimate of Hg Inhalation Exposure Potential." Memo from Alan Stern to Eileen Murphy. Division of Science and Research, NJDEP, October 15, 1997.

Stern, A.H., M. Gochfeld, C. Weisel and J. Burger (2001) Mercury and methylmercury exposure in the NJ pregnant population, Arch. Environ. Health., in press.

Stern, A.H., Korn, L.R., and Ruppel, B.E. (1996) Estimation of fish consumption and methylmercury intake in the New Jersey population. J. Exposure Analysis Env. Epidemiology 6:503-527.

Stevenson, E., R. England, & B. Ruppel (1995) A pilot study to assess trace levels of mercury in New Jersey lakes and precipitation, NJDEP-DSR Research Project Report, August 1995, 22 pp.

Stoewsand, G.S., C.A. Bache and D.J. Lisk (1974) Dietary selenium protection of methylmercury intoxication of Japaneses quail, Bull. Environ. Contam. Toxicol 11(2):152-156.

Styrishave, B. And M.H. Depledge (1996) Evaluation of mercury-inducted changes in circadian heart rate rhythms in the freshwater crab, *Potamon potarnios*, and the crayfish, *Astacus astacus*, as an early predictor of mortality, Comparative Biochemistry and Physiology A-Physiology 115(4):349-356.

Sutton, C.C., J.C. O'Herron, II, and R. T. Zappalorti (1996) The scientific characterization of the Delaware Estuary. A publication of the Delaware Estuary Program.

Sweet, C., E. Prestbo, and B. Brunette (1999) Wet deposition of mercury in the US and Canada, presented at "Mercury in the Environment Specialty Conference," September 15-17, 1999, Minneapolis, MN, Proceedings published by Air and Waste Mgmt. Assoc., Pittsburgh, PA.

Tejning, S. (1967) Biological effects of methyl mercury dicyandiamide treated grain in the domestic fowl Gallus gallus L. Oikos 1967 Suppl. 8:1-116.

Thompson D.R., R.W. Furness and R.T. Barrett (1992) Mercury concentrations in seabirds from colonies in the northeast Atlantic, Arch Environ Contam Toxicol.23:383-389.

Thompson, D.R. and R.W. Furness (1989) Comparison of the levels of total and organic mercury in seabird feathers, Marine Pollution Bull. 20:577-579.

Thompson, D.R., R.W. Furness and L.R. Monteiro (1998) Seabirds as biomonitors of mercury inputs to epipelagic and mesopelagic marine food chains. Science Total Environ. 213:299-305.

Toxics in Biota Committee (1994) Mercury Contamination in New Jersey Freshwater Fish - Report of the Toxics in Biota Committee. New Jersey Department of Environmental Protection, New Jersey Department of Health, New Jersey Department of Agriculture. July 1994.

United States Geological Survey (USGS) (1997) Mercury in Ground Water, Soils, and Sediments of the Kirkwood-Cohansey Aquifer System in the New Jersey Coastal Plain. Open-File Report 95-475. US Geological Survey, West Trenton, NJ.

US Department of Energy (USDOE) (1994) National Environmental Research Parks. Washington, DC.

US Fish and Wildlife Service (USFWS) 1990. Concentrations of organochlorines and trace elements in fish andBlue Crabs from the Delaware River. Easton to Deepwater. Pennsylvania Field Office, Rept. N. 90:5-05. United States Fish and Wildlife Service, 19 pp.

US Food and Drug Administration (USFDA) (1994) FDA Consumer Report, Consumpiton advice on eating shark and swordfish.

US Environmental Protection Agency (USEPA) 1991. ECOTOX: Ecological Database. Office of Research and Development.

US Environmental Protection Agency (USEPA) (1992) National Study of Chemical Residues in Fish vols. I and II. Report # 823-R-92-008 Washington DC: US Environmental Protection Agency.

US Environmental Protection Agency (USEPA) (1992a) Guidelines for Exposure Assessment. USEPA/600Z-92/001. FR 57: 22888 - 22938

US Environmental Protection Agency (USEPA) (1992b) Characerization of products containing mercury in municipal solid wastes in the US, 1970 to 2000, USEPA 530-R-92-013, USEPA, Office of Solid Waste and Emergency Response.

US Environmental Protection Agency (USEPA) (1993) National Fish Tissue Data Repository, USEPA, Washington, DC.

US Environmental Protection Agency (USEPA) (1995a) Method 669. Sampling ambient water for trace metals at EPA water quality criteria levels. USEPA. 821-R-95034.

US Environmental Protection Agency (USEPA) (1995b) The use of the benchmark dose approach in health risk assessment. Office of Research and Development, Washington, DC: USEPA/630/R-94/007, February, 1995

US Environmental Protection Agency (USEPA) (1998) An SAB Report: Review of the USEPA Draft Mercury Study Report to Congress. USEPA-SAB-EC-98-001. October 1997.

US Environmental Protection Agency (USEPA) (1997c) Mercury Study Report to Congress. Vol. 3: Fate and Transport of Mercury in the Environment, USEPA-452/R-97-003. US Environmental Protection Agency, Washington, DC.

US Environmental Protection Agency (USEPA) (1997b) Mercury Study Report to Congress. Vol. 4: An Assessment of Exposure to Mercury in the United States. USEPA-452/R-97-006.

US Environmental Protection Agency (USEPA) (1997c) Mercury Study Report to Congress, Vol. 5: Health Effects of Mercury and Mercury Compounds. USEPA-452/R-97-007.

US Environmental Protection Agency (USEPA) (1997e) Mercury Study Report to Congress, Vol. 7: Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States. USEPA-452/R-97-009.

US Environmental Protection Agency (USEPA) (1999b) National Recommended Water Quality Criteria. USEPA 822-Z-99-001. Office of Water.

US Environmental Protection Agency (USEPA) 1999c. Passaic River Study Area. Fact sheet. Web page: ww.epa.gov/region02/superfnd/pass-ou2.htm.

US Environmental Protection Agency (USEPA) (2000) Workshop on Source Emission and Ambient Air Monitoring of Mercury: Bloomington, MN September 13-14, 1999. USEPA/625/R-00/002) June 2000.

US Environmental Protection Agency (USEPA (2001) Water quality criterion for protection of human health: Methylmercury - Final. USEPA-823-R-01-001.

United States Food and Drug Administration (USFDA) (1992) Compilation of Methylmercury Results by Species for FY91 and FY92. Office of Seafood. Washington, D.C.

Vahter M, A. Akesson, B. Lind, U. Bjors, A. Schutz and M. Bergluund (2000) Longitudinal study of methylmercury and inorganic mercury in blood and urine of pregnant and lactating women, as well as in umbilical cord blood. Environ. Research 84:186-194.

Van Metre P.C. & E. Callendar (1997) Study plan for the reconstructed trends project of the National Water Quality Assessment Program. Website: http://tx.usgs.gov/coring/approach.html United States Geological Survey. 1999. National Water Quality Assessment Program.

Varanasi, U., J.E. Stein, K.L. Tilbury, J.P. Meador, C.A. Sloan, D.W. Brown, J. Calambokidis, and S. Chan. (1993) Chemical contaminants in Gray Whale (Eschrichtius robustus) stranded in Alaska, Washington, and California, USA. NOAA Technical Memorandum NMFS-NWFSC-11, 115 p.

Vermeer, K., F.A.J. Armstrong and D.R.M. Hatch (1973) Mercury in aquatic birds at Clay Lake, western Ontario. J. Wildlife Manage. 37:58-61.

Versar, Inc. (1994) Estimates of contaminant inputs to the Delaware Estuary from nonpoint sources. Contract report to the Delaware Estuary Program.

Verta M. (1990) Changes in fish mercury concentrations in an intensively fished lake. Can J Fish Aquatic Sci 47:1888-1897.

Wagemann, R. and D.C.G. Muir. (1984) Concentration of heavy metals and organochlorines in marine mammals of northern waters: overview and evaluation. Canadian Technical Report of Fisheries and Aquatic Sciences 1279.

Wang, A., Barber, D., and Pfeiffer, C.J. (2001) Protective effects of selenium against mercury toxicity in cultured Atlantic Spotted Dolphin (Stenella plagiodon) renal cells. Arch. Environ. Contam. Toxicol. 41:403-409.

Weihe, P., P. Grandjean, F. Debes, and R. White (1996) Health implication for Faroe Islanders of heavy metals and PCBs from Pilot Whales. Science Total Environ. 186:141-148.

Wiener, J.G. (1996) Mercury in fish and aquatic food webs. Paper presetned at US Geological Survey meeting, "Merucyr Cycling in the Environment," USGS, Office of Water Quality, Denver, CO.

Weis, J.S. and A.A. Khan (1990) Effects of mercury on the feeding behavior of the Mummichog, Fundulus heterolcitus, from a polluted habitat. Marine Environ Research 30:243-249.

Weis, J.S., and A.A. Khan (1991) Reduction in prey capture ability and condition in mummichogs from a polluted habitat. Trans. AM. Fish. Soc. 120: 127-129.

Weis, J. S. and P. Weis. (1977a) Effects of heavy metals on development of the killifish, Fundulus heteroclitus. J. Fish Biology, 11:49-54.

Weis, P. and J. S. Weis. (1977b) Methylmercury teratogenesis in the killifish, Fundulus heteroclitus. Teratology, 16:317-326.

Weis, J.S. and P. Weis (1989) Tolerance and stress in a polluted environment: the case of the Mummichog. BioScience 39:89-95.

Weis, J.S. and P. Weis (1995a) Swimming performance and predator avoidance by mummichog (Fundulus heteroclitus) larvae after embryonic or larval exposure to methylmercury. Can J Fish Aquatic science 52: 2168-2173.

Weis, J.S. and P. Weis (1995b) Effects of embryonic exposure to methylmercury on larval prey-capture ability in the Mummichog, Fundulus heteroclitus. Environ Toxicol Chemistry 14:153-156, 1995b.

Weis, J. S., P. Weis, and J.L. Ricci. (1981) Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (Fundulus heteroclitus) Rapp. P.-v. Réun. Cons. int. Explor. Mer, 178:64-70.

Wester, P.W. (1991) Histopathological effects of environmental pollutants B-HCH and methylmercury on reproductive organs in freshwater fish. Comp. Biochem. Physiol. 100C: 237-239.

Wiemeyer, S.N., D.M. Bunck, and C.J. Stafford (1993) Environmental contaminants in Bald Eagle eggs - 1980-1984 - and further interpretations of relationships to productivity and shell thickness. Arch. Environ. Contam. Toxicol. 24:213-227.

Wiemeyer, N., R.M. Jurek, and J.F. Moore (1986) Environmental contaminants in surrogates, foods and feathers of California Condors (Gymnogyps californianus) Environ. Monitor. Assess. 6:91-111.

Wiemeyer, S.N., T.G. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser and M.A. Byrd. (1984) Organochlorine pesticide, polychlorobiphenyl, and mercury residues in Bald Eagle eggs - 1969-1979 - and their relationship to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

Wiener, J.G., W.F. Fitzgerald, C.J. Watras and R.G. Rada (1990) Partitioning and bioavailability of mercury in an experimentally acidified lake, Enviorn. Toxicol. Chem. 9:909-918.

Windom, H.L and D.R. Kendall (1979) Accumulation and biotransformation of mercury in coastal and marine biota pp. 303-324. in Nriagu, J.O. (ed) The Biogeochemistry of Mercury in the Environment. Elsevier-North Holland Press, Amsterdam.

Windom, H.L. & R.G. Smith, Jr. (1992) Analysis of mercury species in ground water using inductively coupled plasma - mass spectrometry and gas chromatography, Final Report to NJDEP, September, 30 pp.

Wobeser, G. (1975) Prolonged oral administration of methylmercury chloride to Rainbow Trout (*Salmo giardneri*) J. Fish. Res. Board Can. 32: 2015-2023.

World Health Organization (WHO) (1990) Environmental Health Criteria; 101, Methylmercury. Geneva, Switzerland.

World Health Organization (WHO) (1991) Inorganic Mercury. Environmental Health Criteria 118. Geneva.

Yanochko, G.M., Jagoe, C.H. and Brisbin, I.L. Jr. (1997) Tissue mercury concentrations in Alligators (*Alligator mississippiensis*) from the Florida Everglades and the Savannah River Site, South Carolina. Arch. Environ. Contam. Toxicol. 32:323-328.

Yess, N.J. (1993) US Food and Drug Administration Survey of Methyl Mercury in Canned Tuna. J. AOAC International 76:36-38.

Zallups, R.K. (1997) Renal toxicity of mercury. Pp. 633-652 in Comprehensive Toxicology vol. 7: Renal Toxicology (Sipes I.G., McQueen, C.A. and Gandolfi, A.J., eds) Pergamon Press, New York.

Zdanowicz, V.S. and D. Gadbois (1990) Contaminants in sediment and fish tissue from estuarine and coastal sites of the northeastern United States : data summary for the baseline phase of the National Status and Trends Program Benthic Surveillance Project, 1984-1986. : U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Mass, 138 pp.

Zillioux, E.J., D.B. Porcella and J.M. Benoit (1993) Mercury cycling and effects in freshwater wetland ecosystems, Environ. Toxicol. Chem. 12: 2245-2264.

New Jersey Mercury Task Force

Volume III:
Sources of Mercury in New Jersey

Mercury-Containing Products: A Significant Source

January, 2002

Prepared for New Jersey Department of Environmental Protection

New Jersey Mercury Task Force Report
Volume III
Sources of Mercury in New Jersey

January, 2002

New Jersey Mercury Task Force

Donald T. DiFrancesco
Acting Governor

Robert C. Shinn, Jr.
Commissioner

State of New Jersey

Christine Todd Whitman
Governor

Department of Environmental Protection

Robert C. Shinn, Jr.
Commissioner

Department of Environmental Protection
Commissioner's Office
401 East State Street, 7th Floor
P.O. Box 402
Trenton, NJ 08625-0402

Dear Reader:

Mercury is a persistent, bioaccumulative, toxic pollutant. An organic form of mercury (methylmercury) has been found at unacceptably high levels in certain fish, and can cause serious health effects in some fish consumers. Other exposure routes are also potentially important, including exposure to primarily inorganic forms of mercury in some private well water.

Through a combination of source reduction and aggressive pollution control measures, we in New Jersey, have achieved some very notable reductions in the environmental releases of mercury over the past decade including reductions in emissions from municipal solid waste and medical waste incinerators.

More significant reductions are feasible and necessary. The Mercury Task Force recommends a strategic goal of an 85% decrease in in-state mercury emissions from 1990 to 2011. (This goal equates to a 65% decrease from today to 2011.) At my request, the Mercury Task Force has diligently assembled a vast body of information to serve as the basis for a comprehensive set of recommendations to reduce the environmental impacts of mercury releases. These recommendations are designed to provide New Jersey with its first comprehensive mercury pollution reduction plan. Implementation of these recommendations will limit mercury exposures to our citizens and our wildlife.

I would like to thank all of the Task Force members for their hard work and dedicated service to the citizens of New Jersey, and I am pleased to accept this comprehensive Mercury Task Force Report. I urge legislators, government officials, the environmental community, business and industry, the scientific and technical community, and all other interested citizens to review this report and determine how they can most effectively work in partnership with the New Jersey Department of Environmental Protection and other state agencies, to achieve these important New Jersey mercury reduction goals.

Sincerely,

Robert C. Shinn, Jr.
Commissioner

E O H S I

ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES INSTITUTE

University of Medicine & Dentistry of New Jersey
Department of Environmental and Community Medicine
EOHSI Building---170 Frelinghuysen Road
Piscataway, NJ 08854
Phone 732-445-0123 X627 FAX 732-445-0130
email "gochfeld@eohsi.rutgers.edu"

November 2001

Commissioner Robert C. Shinn, Jr.
NJ Department of Environmental Protection
P.O. Box 402
Trenton, NJ 08625-04002

Dear Commissioner:

The members of the Task Force are pleased to submit to you our recommendations for reducing mercury impacts to the environment.

Mercury is a highly toxic material that has no known essential biological properties. It is toxic to adults, but the main health concern today is its potentially profound impact on the developing nervous system and the concern that fetal development can be significantly altered by even low levels of mercury (particularly methylmercury) in the mother's diet. This growing concern, spurred by recent epidemiologic research, has led many governments and other groups to address the problem of mercury in the environment.

Mercury's unique physical properties have led to its use for centuries in a wide variety of commercial applications and industrial processes. Its toxic properties have also been exploited in medicine, dentistry, agriculture, and paint manufacture. Although most uses have been eliminated or reduced (for example, mercury fungicides and batteries), or are being phased out today (for example, mercury thermometers), mercury remains in commerce in a number of forms including dental amalgams, fluorescent lights, thermostats, and certain electric switches.

Today, however, many of the most serious sources of mercury are inadvertent. These include the burning of waste, the use of coal to generate electricity, and the recycling of a variety of mercury-containing products, such as metals. Recognizing that toxic methylmercury occurred at surprisingly high levels in some freshwater fish from many waterbodies in the State, the New Jersey Department of Environmental Protection convened the first Mercury Task force in 1993. This advisory group concluded that emissions from municipal solid waste incinerators were, at that time, the main controllable sources of mercury emissions in the state. Its recommendations and subsequent regulations led to a major reduction in mercury emissions from New Jersey incinerators; the targets set by the first Task Force for this particular industrial sector have been met and surpassed.

It has been my privilege to chair the second Mercury Task Force, convened in 1998 by Commissioner Robert C. Shinn, Jr., which has tackled a much wider array of mercury sources. Triggered, in part, by the concern that energy deregulation would increase the output from midwestern power plants which, as a whole, have relatively high emissions including mercury, the Task Force had to grapple at the outset with recommendations to assure that New Jersey's own energy deregulation law would not exacerbate New Jersey's mercury pollution problem. The Task Force went on to inventory many other sources of mercury to the environment, some of them unanticipated.

Our work has been rendered at times easier, and at times more difficult, by the many reports from federal agencies, other states, non-governmental organizations, and public interest groups that have appeared during the lifetime of the Task Force. New Jersey is by no means alone in considering various approaches, including legislation, to reduce mercury uses and emissions. It has indeed been an exciting time to learn about mercury.

For three years now I have had the opportunity to work with and learn from many dedicated and knowledgeable Task Force members and NJDEP representatives. We have also benefited from the numerous presentations made to the Task Force by outside groups, each with unique knowledge and perspectives. They are identified in Appendix VI.

Work on a voluntary Task Force of this nature is extremely demanding of time and energy. A number of Task Force members and other stable participants were indefatigable in their participation, and I particularly want to thank:

William Baker
Andrew Bellina
Janet Cox
Daniel Cunningham
Robert Dixon
Tom Fote
Betty Jensen
Russ Like
Jerry Marcus
Leslie McGeorge (NJDEP Representative)
Keith Michels
Robert Morris
Joel O'Connor
Valerie Thomas
Robert Tucker

Also, Dolores Phillips played a very active role in the origin and early deliberations of the Task Force.

Many NJDEP representatives contributed to the research and writing of the report. All are listed in Appendix IV.

I particularly thank Bob Morris, Alan Stern and Michael Aucott whose time commitments to the Task Force were great and who each co-chaired one of the two working sub-committees (Impacts and Sources). Leslie McGeorge coordinated all

NJDEP technical support for the Task Force, kept the Task Force focused on its charges and integrated its work with other NJDEP projects and programs. Sue Shannon coordinated various aspects of the Task Force and managed the communications and planning of meetings.

Other NJDEP staffers who made major contributions include:

Sunila Agrawal
Alan Bookman
Gary Buchanan
Robert Confer
Jim DeNoble
Mary Downes-Gastrich
Randy England
Joann Held
Mike McLinden
Eileen Murphy
Bill O'Sullivan
Anthony Pilawski
Bruce Ruppel
Michael Winka

I personally thank Commissioner Shinn for the thoughtful organization of the Task Force and his patience in awaiting this report. I trust that it will prove valuable in helping New Jersey and the Nation grapple with an insidious pollutant and reduce its impact on future generations. I echo his charge, that the lessons learned from mercury toxicity, mercury pollution and mercury control, should also help us in reducing human and ecosystem exposure to other environmental hazards which can threaten our growing population.

Sincerely yours,

Michael Gochfeld, MD, PhD
Chair

Charge to the Mercury Task Force
From Administrative Order 1998-08
Signed by Commissioner Shinn in March 1998

The mission of the Task Force is to develop a mercury pollution reduction plan for New Jersey. The Task Force is directed to complete the following tasks:

1. Review the current science on: a) impacts of mercury pollution on public health and ecosystems; and b) mercury deposition, transport, and exposure pathways.

2. Inventory and assess current sources of mercury pollution to the extent feasible, including both in-state and regional sources of mercury pollution.

3. Utilizing available information, quantify mercury pollution's impact on New Jersey's ecosystems, public health, and tourism and recreation industries.

4. Review New Jersey's existing mercury pollution policies.

5. Develop a mercury pollution reduction plan for the State of New Jersey, including:
    A) Recommend mercury emission controls and standards for in-state sources, including: coal fired generators; hazardous waste incinerators; sludge incinerators; hospital waste incinerators; and for other sources deemed necessary by the task force. In recommending controls and standards, the task force will explore renewable energy and alternative fuels to mercury emitting fuels now in use, and review innovative and low cost emission reduction strategies available in various industrial sectors.
    B) Provide timely interim recommendations, as feasible, prior to completion of the task force's overall mission, to the New Jersey Department of Environmental Protection, New Jersey Board of Public Utilities, other state agencies, interstate agencies, and the federal Environmental Protection Agency regarding mercury pollution, mercury pollution controls and standards and the relationship of energy deregulation to mercury pollution.

NJ Mercury Task Force
Final Report

Volume I
Executive Summary and Recommendations

Volume II
Exposure and Impacts

Volume III
Sources of Mercury to New Jersey's Environment

Volume III, Chapter 1: Overview of Sources of Mercury to New Jersey's Environment

A. Introduction

There are both natural and anthropogenic sources of mercury to the environment. The anthropogenic sources are many, and varied. This section describes the various anthropogenic sources in New Jersey that have been identified and estimated by the Task Force, and summarizes the inventory of anthropogenic sources. To provide a context for the various sources, a materials accounting of mercury in New Jersey is also presented. This accounting depicts estimated yearly flows of anthropogenic mercury in New Jersey, and also provides estimated reservoir quantities where possible. Also, to provide additional context, this section categorizes sources in the following three different ways:

1) Medium into which the source is released (air, water, soil, or disposal repository);
2) Reason for mercury's presence in the release; either intentionally added at some point in a product's life cycle, or present as a contaminant in a raw material; and
3) Sector from which the release occurs; residential, commercial, industrial, agricultural, government facility, utility or transportation.

Volume III, Chapter 3 presents details on each of a number of separate sources and source categories identified and researched by the Task Force.

B. Global, Regional, and Local Contributions to NJ's Environment

Mercury has long been used in commerce in a variety of products and applications, and it is an inherent contaminant of fossil fuels. There is ample evidence that global mercury deposition rates and background atmospheric concentrations have increased significantly over the past 150 years.[1,2] In one study, mercury accumulation rates in Great Lakes' sediments were found to have increased by factors ranging from 50 to over 200 from pre-industrial to modern times.[3] Even in relatively remote areas, mercury accumulation rates appear to be 3 or more times higher now than before the industrial age.[4,5] High levels of mercury in the environment are cause for concern primarily because a portion of that mercury is converted to methyl mercury, which accumulates in fish to levels that can harm humans and wildlife that consume the fish. Also, high mercury concentrations in air, usually due to spills in indoor environments, and mercury contamination of groundwater may be a concern.

---

[1] Slemr, F., and E. Langer, 1992, Increase in global atmospheric concentrations of mercury inferred from measurements over the Atlantic Ocean, *Nature, 355*, 434-437.

[2] Fitzgerald, W. D. Engstrom, R. Mason, and E. Nater, 1997, The Case for atmospheric mercury contamination in remote areas, *Environ. Sci. Technol, 32, 1-7.*

[3] Pirrone, N., I. Allegrini, G. Keeler, J. Nriagu, R. Rossmann, and J. Robbins, 1998, Historical atmospheric mercury emissions and depositions in North America compared to mercury accumulations in sedimentary records, *Atmospheric Environment*, 32, 929-940.

[4] Lorey, P., and C. Driscoll, 1999, Historical trends of mercury deposition in Adirondack Lakes, *Environ. Sci. Technol*, *33*, 718-722.

[5] Swain, E. B., D. Engstrom, M. Brigham, T. Henning, and P. Brezonik, 1992, Increasing rates of atmospheric mercury deposition in mid-continental North America, *Science, 257*, 784-787.

Although there are natural emissions of mercury, it is believed that current global anthropogenic emissions are between 3600 and 4500 metric tons (8 to 10 million pounds) per year. The anthropogenic portion represents from 67% to greater than 75% of the yearly total global input.[6,7] The impact of anthropogenic emissions has led to a factor of three increase in the concentration of mercury in surface ocean waters over the last 150 years.[8] (The long times required for complete circulation of ocean water, on the order of 1000 years, mean that the deeper layers are still relatively uncontaminated by the recent human perturbations.) So-called natural emissions, many of which emanate from the surface of the oceans, are believed to include a sizeable component of recycled mercury that came originally from anthropogenic sources.[9] (See previous discussion of mercury in the environment and its transport and fate in Volume II, Chapter 1.)

The primary route of exposure in humans is consumption of fish contaminated with mercury. The principal mercury source to remote lakes is air deposition. Air deposition is also the main contributor to the oceanic burden of anthropogenic mercury, with rivers contributing only about 10% of the total mercury input to the world's oceans.[10] In New Jersey, while there are estimated to be relatively large discharges to some water bodies, the largest (in mass) mercury input to the environment is also believed to be air deposition. Air emissions are estimated to comprise the largest group of releases entering the ambient environment from which the mercury could eventually make its way to fish tissue. Uncertainties in these estimates remain. One uncertainty is the amount of mercury possibly recycled to a bioavailable form during dredging of mercury-containing sediments.

A materials accounting estimate for New Jersey has been developed. See Figure III.1.1, below. The figure depicts yearly flows in thousands of pounds where estimates are possible. Flow quantities, represented by arrows in the figure, represent one year's flow. In this figure, mercury inputs to the State in the form of raw materials and products, and outputs in many forms, including air emissions, direct releases to water and land, and transport to disposal facilities are shown.

Also shown in the figure are inputs to the state from wet and dry deposition from the atmosphere, which is the route by which it is believed most mercury that eventually becomes biologically available enters the environment. This quantity is a function of the quantity of mercury present in the atmosphere over New Jersey, and of the factors that lead to the conversion of this mercury into forms that are incorporated into precipitation or which are susceptible to dry deposition. This quantity is influenced by both in-state emissions and mercury transported into the state from elsewhere.

---

[6] Mason, R. and W. Fitzgerald, 1996, The Global Mercury Cycle: Oceanic and Anthropogenic Aspects, in W. Baeyens et al. (eds.), *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*, 85-108. Kluwer Academic Publishers, Netherlands.

[7] Fitzgerald, W., personal communication, June, 2001.

[8] Mason, R, W. Fitzgerald, and F. Morel, 1994, Biogeochemical cycling of elemental mercury: anthropogenic influences, *Geochimica Cosmochimica Acta. 58*, 3191-3198.

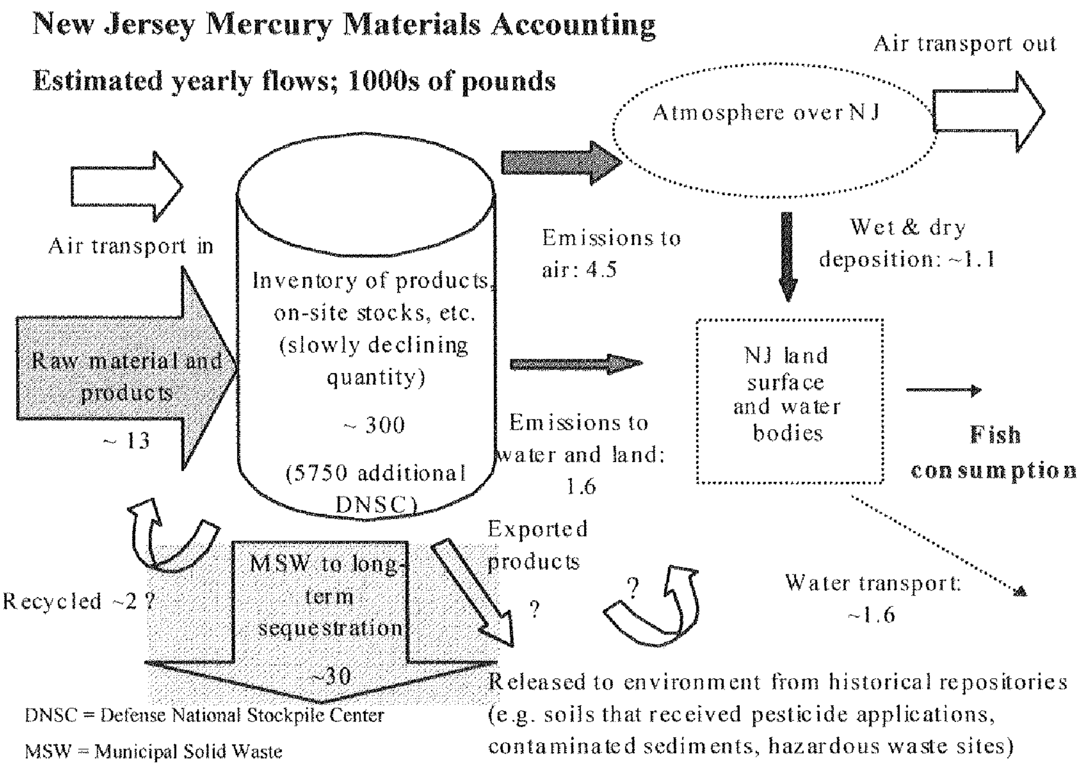
[9] Mason, Fitzgerald, Morel, 1994.

[10] Mason and Fitzgerald, 1996.

Also shown are vectors representing unknown or difficult to quantify fluxes of mercury. One such unknown flux is the release of mercury from historical repositories, which include the land surface and sediments. Another flux that is difficult to characterize in a materials accounting context is the mercury entrained in the atmosphere that flows across the state without depositing. This flux is likely to be large, but is not as relevant as the portion of that flux that becomes wet and dry deposition.

Also shown in the figure is the estimated inventory quantity. This includes mercury present in products and other items within the human environment, such as thermostats, thermometers, and dental amalgam. It is estimated that this inventory is slowly shrinking; the outflow, most of which is in the form of municipal solid waste (MSW) going to landfills, is larger than the inflow due to lower than previous use of mercury in products.

Figure III.1.1 1



The inventory of mercury contained in products and substances in use is augmented by 2615 metric tons of mercury stored at the Defense National Stockpile Center (DNSC) in Somerville, NJ, one of four national mercury storage sites. This mercury is stored in flasks in a secure, monitored warehouse. The U.S. defense national stockpile was established after World War II to ensure that the U.S. would have access to commodities needed for defense and other critical uses in times of national emergency. Today, due to changing U.S. defense needs and access to global markets, the mercury in the stockpile has been declared excess. The DNSC is currently preparing a Mercury Management Environmental Impact Statement that will consider alternatives to continued storage at the sites. Alternatives to be considered include: 1) consolidating the mercury at one location for long-term storage; 2) stabilizing the mercury to reduce or eliminate toxicity and then storing or disposing of it; 3) selling it; or 4) leaving it where it is currently stored.

Deposition from the atmosphere is important in the overall cycle. One aspect of this deposition that remains problematic is the determination of its origin. A key difficulty in determining how much mercury deposition is contributed from in-state vs. out-of-state sources is that the mercury species of most emission sources are not well characterized. If an emission from any source is primarily elemental mercury vapor, it would be expected that only a very small percentage of this emission would be deposited in New Jersey. Most emissions of elemental mercury vapor would be expected to waft into the atmosphere and join the global atmospheric pool, which is believed to be primarily elemental mercury vapor. The half-life of atmospheric mercury is estimated to be about one year.[11] Therefore little elemental mercury will deposit near its point of origin. If, however, most of an emission is in the form of mercury bound to particles (e.g., soot) or mercury in the form of Hg^{++}, such as gaseous $HgCl_2$, it is expected that this mercury will deposit relatively near the source of the emission.

Existing data do not permit a definitive determination of how much of the mercury emissions from New Jersey sources is deposited locally. Some reports and models do provide some insight on the relative local and non-local share of deposition, however. It has been estimated, based on models, that perhaps one third of U.S. emissions to the air are deposited within the U.S., with the remainder joining the global atmospheric pool.[12] Other studies suggest that 50% of wet mercury deposition may be accounted for by local or regional sources.[13,14] One study[15] found in Florida (which because it is a peninsula, may not be typical of other regions) over 70% was from relatively local sources. A recent report indicates that deposition rates in relatively non-remote lakes in the upper mid-West have declined recently, but deposition in remote lakes has not declined.[16] This and another recent report[17] suggest that changes in mercury emissions from local sources can have a local impact. Preliminary analysis of data recently made available through the New Jersey Air Deposition Network (NJADN) project[18] also suggest that air deposition

---

[11] Slemr, and Langer, 1992.

[12] USEPA, 1997, *Mercury Study Report to Congress, Volume 1*, EPA-452/R-97-003, p. O-1.

[13] Electric Power Research Institute, 1994, Expert Panel on Mercury Atmospheric Processes. *Mercury Atmospheric Processes: A Synthesis Report*; EPRI/TR-104214; Workshop Proceedings, 1994.

[14] Bullock, O. R., K. A. Brehme, and G. R. Mapp, 1998, *Sci. Total Environ.*, 213,1.

[15] Dvonch, J., J. Graney, G. Keeler, and R. Stevens, 1999, Use of elemental tracers to source apportion mercury in South Florida precipitation, *Environ. Sci. Technol, 33*, 4522-4527.

[16] Engstrom, Daniel, and Edward Swain, 1997, Recent declines in atmospheric mercury deposition in the upper midwest, *Environ. Sci. Technol, 31*, 960-967.

[17] Lindberg, S., and W. Stratton, 1998, *Environ. Sci. Technol 32*, 49-57.

[18] Reinfelder, John, 2000, Report on mercury deposition data from New Jersey Air Deposition Network, 2000, Rutgers University, presented at *Scientific Perspectives on Mercury Management in the Hudson-Delaware Region, Fall Hudson-Delaware SETAC Workshop*, Monmouth University, West Long Branch, NJ, September 29, 2000.

in remote New Jersey regions may be lower than that in urban areas. If most airborne mercury comes from distant sources, more uniform fallout patterns would be expected, and so local and regional sources may be important contributors to deposition quantities. Further, it is currently assumed that between 20 and 80 percent of mercury emissions are elemental (Hg^0) and that the remainder is either gaseous oxidized (Hg^{++}) or on particles.[19] It is expected that the non-elemental forms will deposit relatively locally, especially during rain events.

Based on the reports cited above, it is likely that approximately half of the mercury that is deposited in New Jersey comes from relatively nearby sources. A definitive apportionment of deposition from local, regional, and global sources must await the acquisition of better data on the species of mercury emissions.

A comparison of emissions from in-state sources with deposition estimates based on the data from the NJADN and the national Mercury Deposition Network[20] reveals that New Jersey emissions of mercury are greater than what is deposited from the atmosphere. The state is, from a global perspective, a net exporter of atmospheric mercury. With the intensity of industrial activity, population, and associated uses of mercury-containing products and fuels, a net export of mercury from the state, and from most industrial regions of the world, would be expected.

With its variety of significant mercury uses and mercury sources, New Jersey is in a position to take a leadership role in reducing the releases of mercury to the environment. Because these sources are numerous and varied, an overall understanding of the flows of mercury in industry and commerce is useful. In the discussion that follows, these flows will be explored in more detail and then the various sources will be described and viewed from several perspectives.

Recent research suggests that reductions of anthropogenic emissions of mercury will lead to relatively rapid reductions in concentrations in aquatic species. A Florida modeling study indicated that control of mercury emissions could significantly alleviate the overall Everglades mercury problem within a decade or two.[21] Other research suggests that, in the New York/New Jersey Harbor, the half-life of mercury may be in the range of 20 years.[22] (A half-life of 20 years suggests that, if fresh inputs of mercury are reduced to zero, concentrations of mercury in aquatic species will decline by 50% during the following 20 years.)

---

[19] NESCAUM, NEWMOA, NEIWPC and EMAN, 1998, *Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action.* Northeast States for Coordinated Air Use Management, Boston, MA.

[20] The Mercury Deposition Network is part of the National Atmospheric Deposition Program, http://nadp.sws.uiuc.edu/mdn/. Data from a number of sites reported for the years 1996 through 1999 show wet deposition rates for the Northeastern U.S. in the range of 10 $\mu g/m^2/yr$.

[21] South Florida Water Management District (SFWMA) and Florida Department of Environmental (FLDEP) Protection, 2001, 2001 Everglades Consolidated Report, SFWMA, 3301 Gun Club Road, West Palm Beach, FL, 33406; FLDEP, 2600 Blair Stone Road, Tallahassee, FL 32399.

[22] Mason, Rob, personal communication, August 23, 2001.

C. New Jersey Source Inventory

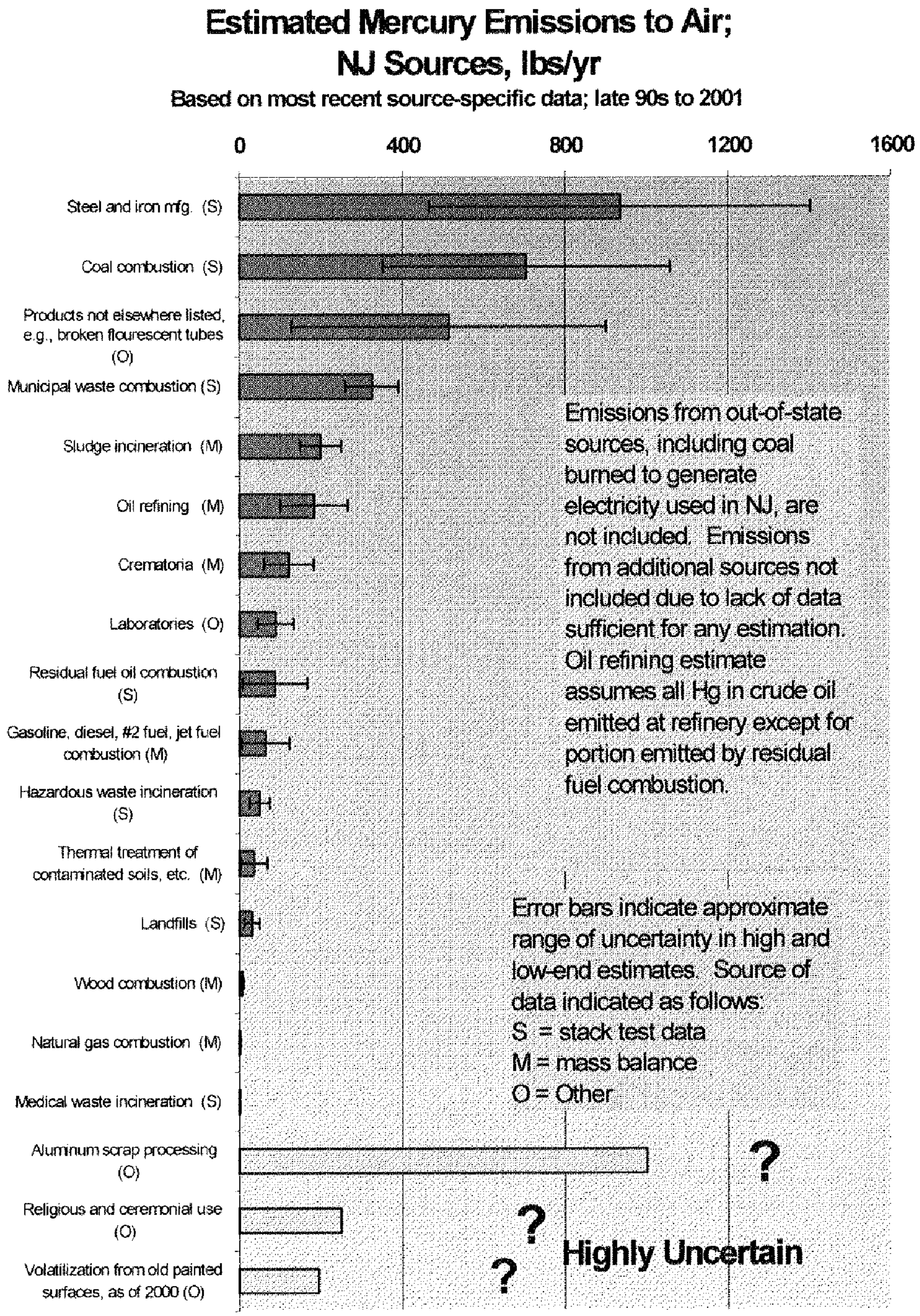
C.1. Releases to air, water, and land

The Task Force estimates that, based on data from the late 1990s and 2000, releases to the air, water, and land are as depicted in Figures III.1.2 and III.1.3. In these figures, estimated uncertainties are shown with the bars extending to the left and to the right of the source bar, representing the range of values in which the real value could reasonably be expected. These uncertainties are judgements reflecting the Task Force's confidence in the numbers. The confidence level of the source quantity is based primarily on the origin of the data, and on the degree of variability in the data that exists. Some of the estimates are based on stack tests performed under the supervision of the New Jersey DEP. Other estimates are based on mass balances which in turn are based on testing results from laboratories that are DEP-approved, or otherwise believed to be reliable, or have been reported in peer-reviewed literature. Still other estimates are derived with other approaches, including engineering judgement based on available information.

Table III.1.1, below, shows the approximate source quantities, medium to which the release occurs, source of the data, and degree of certainty. Degree of certainty in this table is defined as certain (C), moderately certain (MC), or uncertain (U). In this context, certain means the estimated quantity is believed accurate to within ± 50%; moderately certain means believed accurate to within ± 75%, and uncertain means the estimate could easily be inaccurate by more than 75%.

There are source categories that are not shown in Table III.1.1. These include categories for which no estimates are available, such as possible releases of mercury application of sludge-derived products and fertilizers, possible releases of mercury from non-incineration treatment of medical waste, and possible releases of mercury during dredging and subsequent stabilization and deposition of dredged materials. Changes in the Toxic Release Inventory reporting threshold for mercury (from 10,000 lbs./yr. down to 10 lbs./yr.), effective calendar year 2000, are to be reported in July 2001. This information should also provide information regarding industrial releases which may be small individually, but whose cumulative releases could be significant.

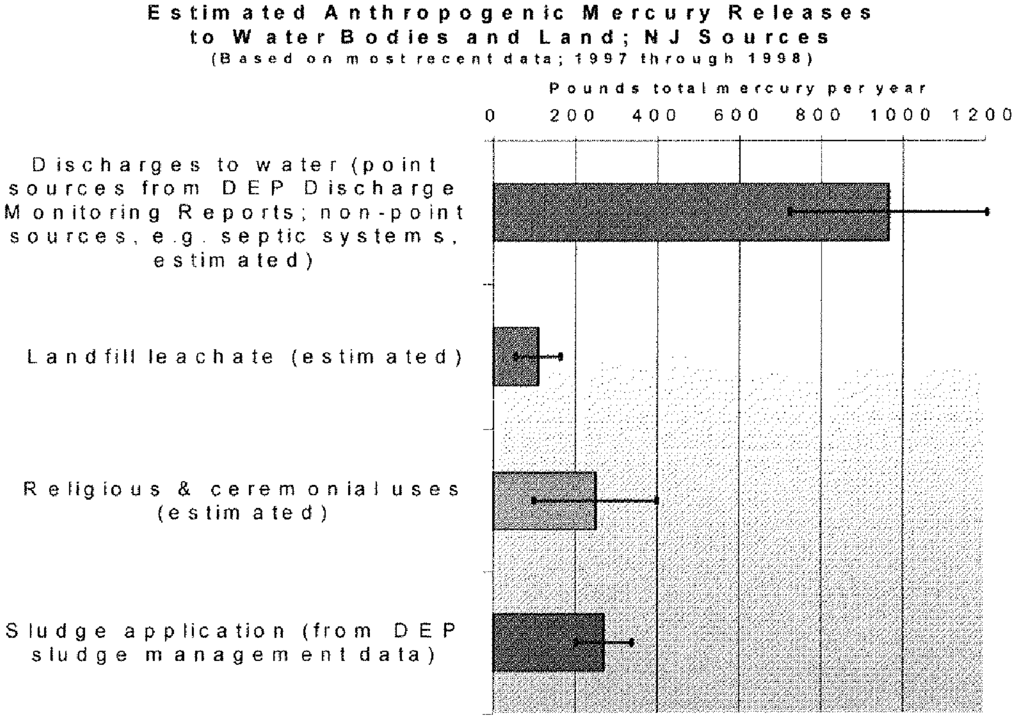
Figure III.1.2. 1



Emissions from out-of-state sources, including coal burned to generate electricity used in NJ, are not included. Emissions from additional sources not included due to lack of data sufficient for any estimation. Oil refining estimate assumes all Hg in crude oil emitted at refinery except for portion emitted by residual fuel combustion.

Error bars indicate approximate range of uncertainty in high and low-end estimates. Source of data indicated as follows:
S = stack test data
M = mass balance
O = Other

Figure III.1.3. 1



Not shown in Table III.1.1 are the species of the mercury emission. This is a poorly understood variable that is important, regarding the distance from a source wherein an air emission can be expected to deposit, and the biological availability of the source. A source relatively small in quantity could still have a large impact on human health or the environment, depending on the species of that source.

Also not shown in Table III.1.1, is the large amount, estimated to be in the range of 300,000 pounds, of mercury present in buildings, equipment, and products in use in New Jersey. Estimated emissions from this reservoir are included under the "volatilization, miscellaneous" category.

An important source category of a different nature is deposition from the air, both dry and wet. Air deposition is the way that most mercury reaches the environment of New Jersey. Current estimates, based on the NJADN project,[23] place the air deposition quantity in the range of 900 to 1200 pounds per year. Further data to be gathered through the NJADN project and other sources will refine this estimate. As discussed above, some, perhaps 50%, of this deposition can be attributed to nearby sources. More research is needed to clarify the relative contribution of in-state and out-of-state sources to the air deposition quantity.

Table III.1.1

---

[23] Reinfelder, John, 2000.

Anthropogenic Mercury Releases and Transfers in NJ (For details, see Chapter 3)

Source category	**Approx. release (lbs./yr.)**	**Medium to which release occurs**	**Source of data (S= stack tests, M = mass balance, O = other)**	**Degree of certainty (C = certain, MC = moderately certain, UC = uncertain)**
Released to water and land				
Surface & ground water[1]	1000	water	M	MC
Landfill leachate	100	water	O	UC
Cultural uses	*250*	water/land	O	*Very uncertain*
Sludge application	250	land	M	MC
Total	**1600**			**MC**
Released to air				
Steel & iron mfg.	1000	air	S	MC
Aluminum scrap processing	*1000*	air	O	*Very uncertain*
Coal combustion	700	air	S	MC
MSW incineration	330	air	S	C
Volatilization (miscellaneous)[2]	300	air	O	UC
Cultural uses	*250*	air	O	*Very uncertain*
Fluorescent tube breakage[3]	240	air	O	UC
Sludge incineration	200	air	M	C
Oil refining	200	air[4]	M	MC
Old painted surfaces[5]	*200*	air	O	*Very uncertain*
Crematoria	100	air	M	MC
Residual fuel combustion	100	air	S	UC
Volatilization (laboratory)	100	air	O	UC
Gasoline, diesel, etc.[6]	50	air	M	UC
Hazardous waste incineration	50	air	S	UC
Thermal treatment[7]	50	air	O	UC
Landfills	40	air	S	C
Wood combustion	10	air	O	MC
Natural gas combustion	5	air	M	MC
Medical waste incineration	5	air	S	MC
Total	**4930**			**MC**
Transferred to NJ disposal sites[8]				
Dredged materials	17,000	na	M	UC
Solid waste (not including out-of-state)	13,600	na	M	MC
Total	**30,600**			**UC**

Notes: [1] Based on NJDEP discharge monitoring reports covering permitted discharges of mercury and mercury compounds to surface and ground water, and augmented by estimated discharges from private septic systems.

[2] Includes estimated volatilization from other mercury-containing discarded items and items in service.

[3] Estimated volatilization from discarded fluorescent tubes during waste handling and processing but before ultimate disposal.

[4] Quantity is relatively certain, based on sampling and analysis of crude oil. Media to which releases may occur are uncertain; assumed to be primarily air, but could include wastewater or other waste streams.

[5] Emissions from this source category are believed to have been sizeable from the 1960s until the early 1990s, when mercury fungicides were removed from paint. It is estimated that emissions have been rapidly declining since the early 1990s. Estimated 2000 emission is approximately 200 pounds/year; it is expected the quantity will approach zero by 2005.

[6] Also includes #2 fuel oil, kerosene, and jet fuel.

[7] Represents emissions from processing of contaminated soils, etc.

[8] Eventual release rate to the ambient environment is unknown.

C.2. Releases based on sector where release originates

Another way to categorize release sources is by the sector from which the release originates. This approach offers insight in developing reduction strategies, particularly those that involve outreach and communication. Source sectors can be considered to be residential (private dwellings), commercial (including retail stores, hospitals, schools and other institutions), industrial (manufacturing facilities), electric power generation, transportation, government (municipal solid waste management and public wastewater management), and agriculture. An apportionment of New Jersey mercury releases by sector is presented in Figure III.1.4. The largest sector is industrial, primarily because of the emissions from iron and steel manufacturing and the inclusion of the potentially large, although not well-characterized, emissions from aluminum manufacturing. Other large sectors include electric power generation (coal combustion), residential (due to apportionment of wastewater and to religious and ceremonial use estimates), and government (which includes municipal solid waste incineration and wastewater treatment plants).

There is not a database that apportions different sources to different sectors. Releases from products during use and waste management were assigned 25% each to industrial, commercial, residential and government. Releases from municipal waste combustion, landfills, and sludge incineration were assigned to government. Volatilization from old painted surfaces was assigned 33% each to industry, commercial, and residential. Releases from coal and residual fuel combustion was assigned to the electric power generation sector. Releases from cultural and ceremonial uses were assigned to the residential sector. Discharges to water were assigned 25% each to the industrial and commercial sectors, and 50% to the residential sector. Releases from sludge application were assigned to agriculture. Releases from laboratories were assigned 50% each to industry and the commercial sector. Releases from gasoline, diesel fuel, kerosene, and jet fuel were assigned to the transportation sector. Other releases were assigned to the industrial sector. All percentages should be assumed to be uncertain.

C.3. Releases based on origin of mercury

Instead of organizing mercury releases based on the medium to which the release occurs (air, water, or land), releases can be organized by the origin of the mercury. There are two broad categories of origin. In one case, mercury can be intentionally added to a product or used directly in an intentional manner. This mercury will then be released, or transferred to a disposal site such as a landfill at some point in the product's life cycle or during the use of the mercury. An example is the mercury used in a measuring device, such as a thermometer. Alternatively, mercury can be present as an unwanted contaminant in a product. Release may occur during use, or through breakage or disposal. An example is the release of mercury during coal combustion.[24] Another example is mercury present at low levels in potable water. When this water becomes

---

[24] Note that the percentage from incidental contaminants in this chart does not include mercury released from coal combusted out-of-state to supply electricity used in New Jersey. See section on coal combustion in Volume III, Chapter 3.

wastewater, the mercury is still present and may become incorporated in wastewater treatment plant sludge, or be included in mercury in a wastewater discharge.

A review of the mercury releases catalogued above suggests that approximately 80% of the mercury released from New Jersey sources is mercury intentionally added to products. See Figure III.1.5. The many points at which mercury can be released to the environment from a product are illustrated in Figure III.1.6, which depicts the mass flow of mercury through the disposal system.

Figure III.1.4 1

Estimated 1999 NJ Anthropogenic Mercury Releases to Air, Water, & Land; by Sector

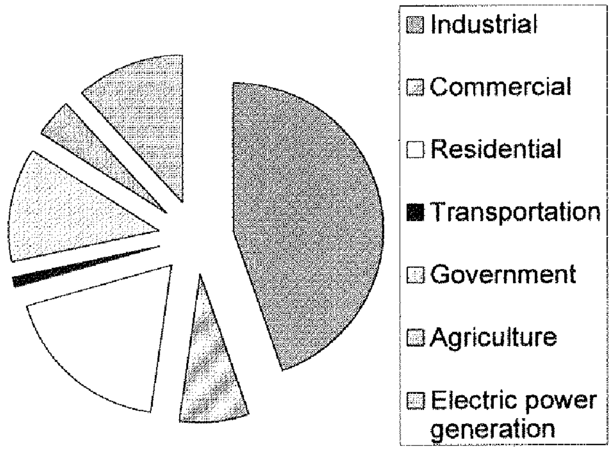


Figure III.1.5. 1

Estimated 1999 NJ Anthropogenic Mercury Releases to Air, Water, & Land; by Origin of Mercury

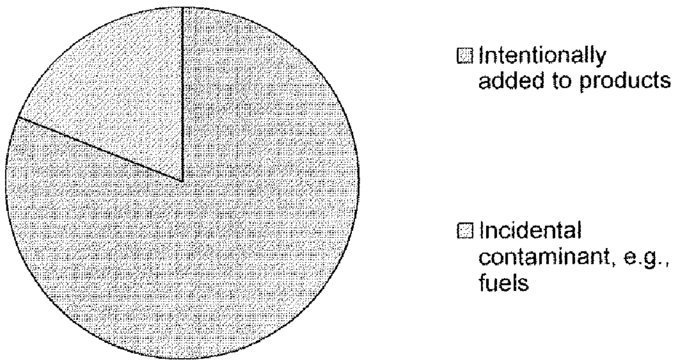
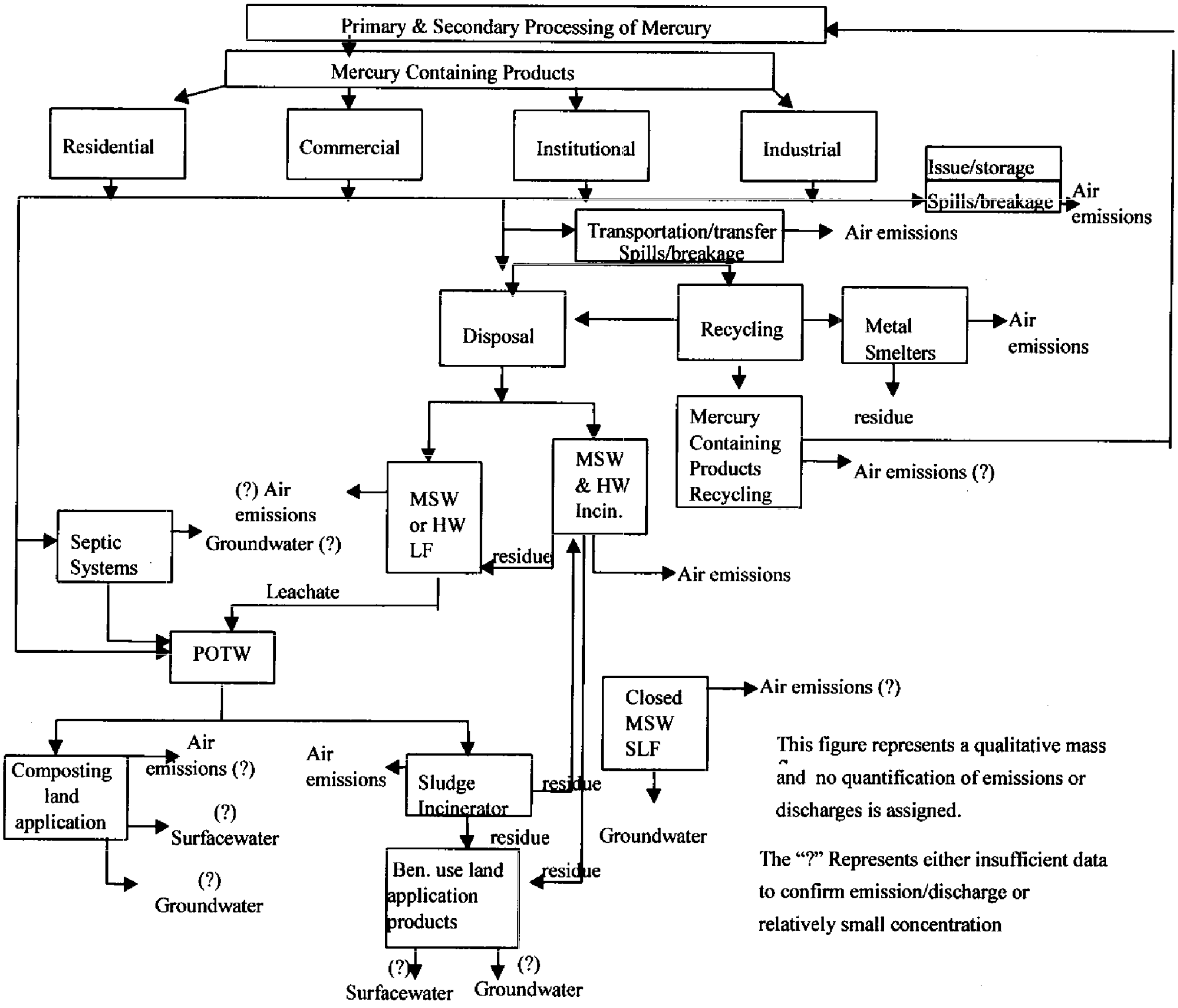


Figure III.1.6. 1

Mass Flow of Mercury Through the Disposal System



This figure represents a qualitative mass and no quantification of emissions or discharges is assigned.

The "?" Represents either insufficient data to confirm emission/discharge or relatively small concentration

POTW = Publicly owned treatment works (sewage treatment plant)
MSW = Municipal solid waste
HW = Hazardous waste
Ben. use = Beneficial use
LF or SLF = Landfill (or sanitary landfill)

Volume III, Chapter 2:
Reduction Recommendations

A. Overall goal

The Task Force advocates an overall goal of virtual elimination of mercury uses and releases. The toxicity and persistence of mercury in the environment, and the statewide existence of high levels of mercury in fish requires that New Jersey move on as many fronts as possible to eliminate additional mercury discharges, emissions, and depositions.

B. Milestones

The Task Force recommends that the State of New Jersey adopt a two-step milestone of 50 percent reduction below estimated 2001 levels by 2006 and a 65 percent reduction below estimated 2001 levels by 2011. This represents an approximately 75 percent reduction below estimated 1990 levels by 2006 and an 85 percent reduction below 1990 levels by 2011, not including additional reductions due to the removal of mercury from paint. Significant reductions in releases to other media are also feasible in this time period, and are in fact likely to occur as a result of the array of efforts required to reduce air emissions. Figures III.2.1., III.2.2, and Table III.2.1 depict the projected reductions by sector.

Achievement of this ambitious and important two-step reduction milestone will require major reductions in air emissions of mercury from all of the large source categories in the state, including coal combustion, steel and iron manufacture, solid waste management, and mercury-containing products in general use. It will also depend upon substantial commitments to mercury pollution prevention on the part of state government agencies, industry and business, and members of the public, including reductions in the amounts of mercury used in manufacturing and a wide range of consumer products. Passage of comprehensive mercury source reduction legislation will greatly facilitate success.

Fortunately, New Jersey has a working model for the multi-media effort needed to reduce mercury- the New Jersey Sustainability Greenhouse Gas Action Plan. Members of the Task Force believe that reducing mercury in the state's air and water, as reducing greenhouse gas emissions, is urgent. The cause of mercury reduction has been taken up by many other states and regions, by U.S. EPA, and by grassroots advocacy groups around the nation. Adoption and implementation of the recommendations in this report will put our state among the leaders of nationwide efforts to protect our families and the environment by preventing this toxic metal from further contaminating our air and water.

Prior Major Reductions

Substantial reductions of mercury release to the New Jersey environment are possible, as demonstrated by the previous reductions. A major advance is the greater than 90% reduction in emissions from municipal solid waste combustion and medical waste combustion since the early 1990s. Combined emissions from these sources are estimated to have been greater than 5000 pounds per year in the early 1990s, and are reduced to approximately 350 pounds per year today. These reductions have been achieved through both emission controls and source reductions. Another major reduction is due to the removal of mercury compounds from paint. Until the early 1990s, emissions of mercury from painted surfaces in New Jersey are estimated to have been greater than 10,000 pounds per year. Today, these emissions are approaching zero, demonstrating the value of pollution prevention by the elimination of mercury-containing biocides from paint, achieved through a combination of voluntary actions by manufacturers and federal requirements. Figure III.2.1 depicts the greater than 80% reduction below estimated 1990 levels by 2011.

Anticipated Reductions in Air Emissions
Table III.2.1. Source categories and basis of estimated reductions
All values in pounds per year

Source category	**Year**				**Basis of estimated change**
	1990	2001	2006	2011	
Non-ferrous & alum processing (approx. est.)	1000	1000	250	100	75% reduction by 2006 due to controls & source reduction, 90% reduction by 2011
Coal combustion (electricity prod.)	705	705	528.75	132	15% red. due to energy conserv. by 2005 plus 10% extra; 75% red by 2011 thru controls
Crematoria	95	125	159	189	Increase in number of cremations
Fluorescent tubes	430	215	75	54	Source reduction of mercury in products, improved practices
Laboratories	89	89	67	45	50% reduction by 2010 due to improved practices
Medical Waste incineration	742	2	2	2	Continuation of existing programs
MSW incineration	4542	349	200	200	Continued reductions through existing programs
Oil refining	184	184	156.4	156	15% reduction due to energy conservation by 2005
Other	127	127	95.25	64	50% reduction by 2010 due to improved practices
Painted surfaces		194	19	2	Continued decline at historical rate
Products in general use	600	300	225	150	Source reduction of mercury in products, improved practices
Refined fuels combustion	156	156	132.6	133	15% reduction due to energy conservation
Cultural and ritualistic uses	250	250	125	63	75% reduction by 2010 due to education, outreach
Sludge incineration	400	200	170	115	Projected emission based on recommended sludge 5 ppm & 2 ppm limits
Iron & steel manufacturing	935	935	234	94	75% reduction by 2006 due to controls & source reduction, 90% reduction by 2011
Totals	**10255**	**4832**	**2439**	**1497**	
percent reduction from 2001			50	69	
percent reduction from 1990			76	85	

C. General recommendations

The Task Force endorses the New England Governors/Eastern Canadian Premiers (NEGECP) Mercury Action Plan goal[1] of virtual elimination of anthropogenic mercury releases in the region.

The Task Force encourages New Jersey to participate in and support regional, national, and global efforts to reduce mercury uses, releases, and exposures. These efforts include the NEGECP Action Plan and other mercury control efforts by Northeast States for Coordinated Air Use Management (NESCAUM), Environmental Council of the States (ECOS), and the USEPA.

---

[1] New England Governors/Eastern Canadian Premiers Mercury Action Plan, 1998, http://www.tiac.net/users/negc/1998mercuryplan.html, June 1998.

The Task Force recommends the removal of mercury from products and the phase out of sales of mercury-containing products where there are reasonably available alternatives. The Task Force also recommends adoption of legislation and executive orders addressing mercury sources, in order to reduce mercury emissions, depositions, and discharges from a variety of sources, including consumer products. See Table III.2.1 above. The Task Force supports the adoption of legislation that reflects the provisions of the Mercury Education and Reduction Model Act developed by the Northeast Waste Management Officials' Association (NEWMOA).[2] The Task Force urges New Jersey to work with interstate agencies to assist in the development of federal legislation that minimizes the use of mercury in products. New Jersey should also develop effective outreach and education on the importance of removing mercury from products. County household hazardous waste programs should play a key role in this effort.

The Task Force encourages phasing out the use of mercury-containing dental amalgams to the extent compatible with good dental practices, to further limit mercury releases to the environment.

The Task Force encourages New Jersey to use state purchasing and service contracts to reduce the purchase and use of products containing mercury, including motor vehicles containing mercury switches.

The Task Force emphasizes that mercury that is recovered from discarded products or otherwise segregated should be retired and sequestered permanently in a secure facility, rather than being reintroduced to commerce, so that the chances of its being ultimately released to the environment are minimized.

It is important to ensure that substitutes for mercury are not more hazardous than the mercury itself. The Task Force also recommends that replacements or proposed replacements for mercury be scrutinized regarding human and environmental health effects, and that such replacements not be automatically considered desirable merely because they replace mercury.

D. Source-specific reduction recommendations

Members of the Task Force agree that numerous approaches are needed to achieve the 50 percent reduction milestone by 2006. The feasibility of the overall and near-term milestones noted above is based on the Task Force's assessment that numerous approaches exist that can accomplish significant reductions from a variety of sources. The reduction options recommended for each specific source are discussed in detail in the reports on specific sources that appear in Volume III, Chapter 3. The highest priority specific reduction options are listed in Tables III.2.2. and III.2.3. These options were selected by the Task Force using the following procedure:

- Identification, description, and quantification of releases from each source. See discussion in Volume III, Chapter 3.

---

[2] See http://www.newmoa.org/prevention/mercury/programs

- Identification of reduction options for each source. The Task Force included representatives from industry, academia, government, non-profit organizations, and others with expertise in mercury. Task Force and DEP staff members with knowledge of the sources prepared first drafts of the source-specific write-ups and reduction recommendations. Discussions among Sources Subcommittee members refined the list of options. A list of approximately 110 options was developed.
- Categorization of options by type. The options were categorized as to whether they consist of measures to reduce or eliminate the original source and thus prevent mercury pollution (source reduction and best management practices), or whether they rely on end-of- pipe or stack emissions reduction devices (controls). Some options fit into neither category, and were further categorized as research and development or outreach and education approaches.
- Estimate feasibility of achieving each option. Criteria used in estimating feasibility included relative cost and effectiveness of the options.
- Estimate importance of achieving each option. Importance criteria included quantity of release, and also the likelihood that the release could contribute significantly to direct exposure potential or enter biologically-available environmental compartments such as air, surface water, or ground water.
- Prioritize options by feasibility and importance. A working ranking system in spreadsheet format was developed for this effort. In this system, options that were judged to be both important and feasible were ranked highest, those that were important but not feasible were judged medium priority, and those that were considered neither especially important nor feasible were ranked lowest.
- Consolidate prioritized options into final list of high priority recommendations. In this step, Task Force members identified their highest priority options. The Sources Subcommittee further reviewed the Task Force's list of 25 preliminary final choices, and The Task Force recommends that replacements or proposed replacements for mercury be scrutinized regarding human health and environmental options. Finally, the list was consolidated to eliminate redundancies. These final high priority options appear in Tables III.2.2. and III.2.3.
- The full Task Force reviewed the priority list, and suggested additional revisions and improvements.

Figure III.2.1

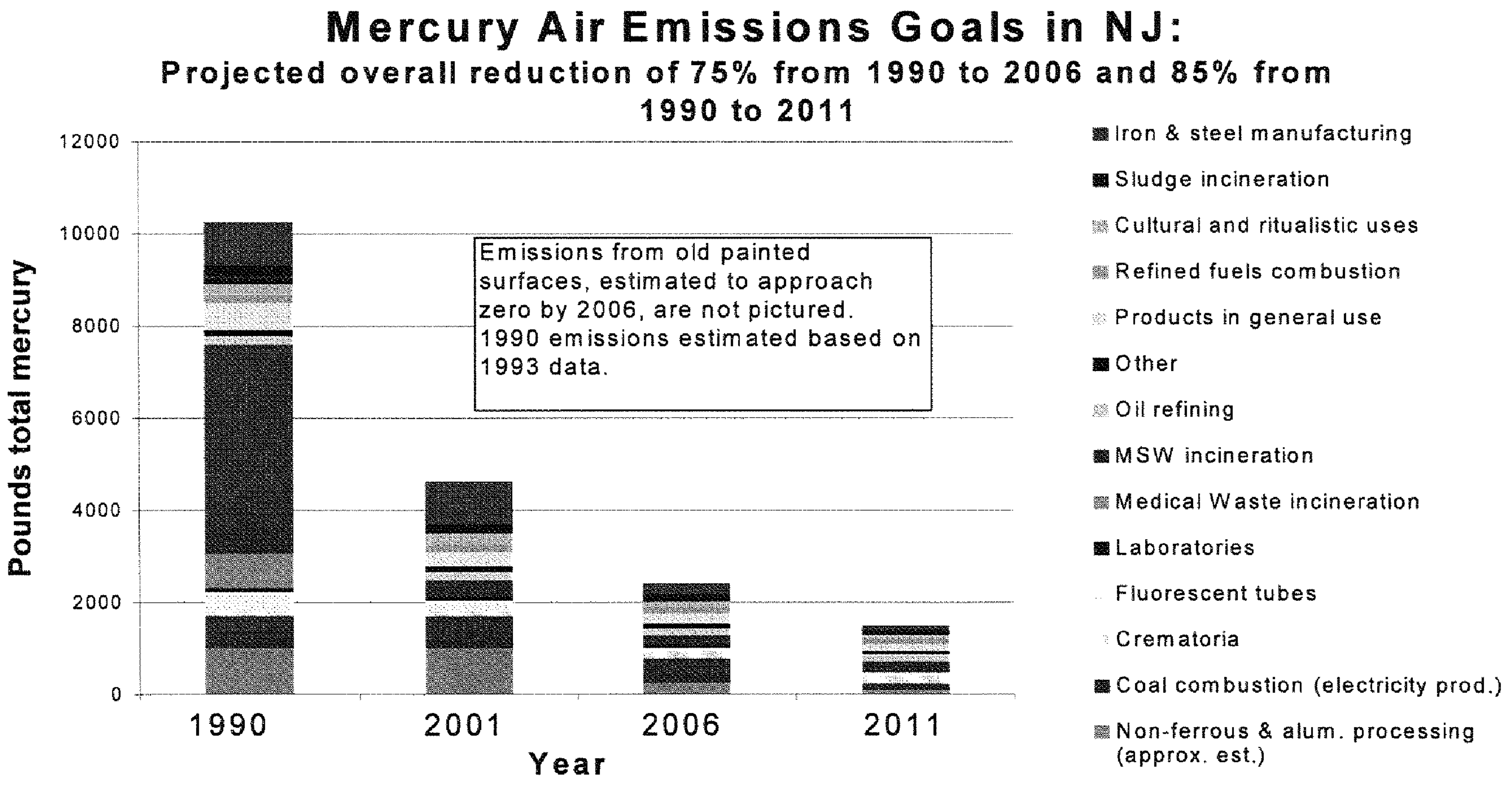
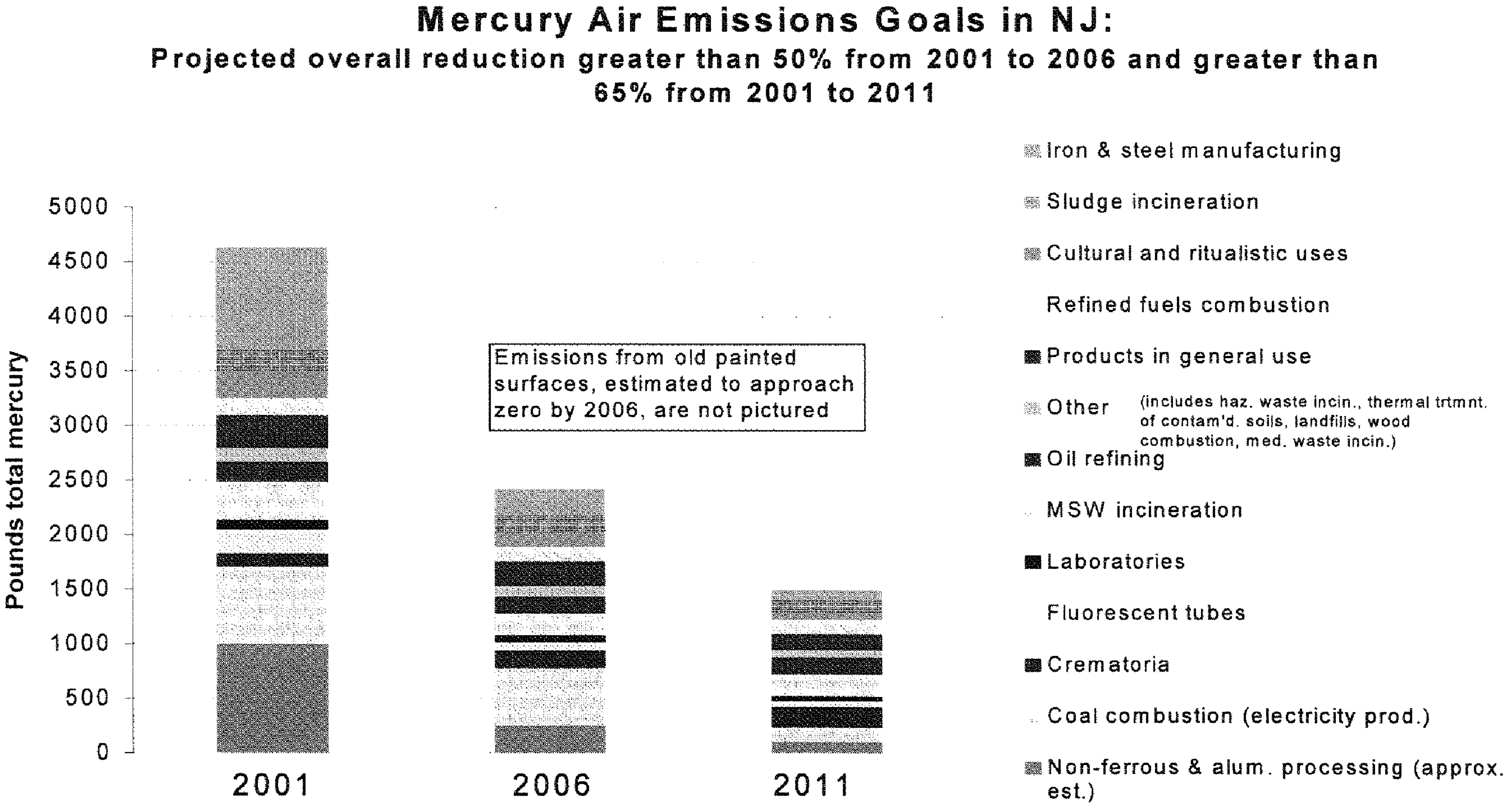


Figure III.2.2 1



III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
SOURCE REDUCTION						
Reduce mercury in products and as a raw material	Sludge; wastewater; air emissions from solid, medical, and hazardous waste management and disposal facilities; indoor emissions from spills	Require labeling showing Hg content, per VT, ME, MN, NEWMOA.	Adopt Northeastern Governors' Mercury Action Plan goal of virtual elimination. State procurement preferences (per NEWMOA)	Increase public awareness of low-mercury products, available alternatives, and disposal options for products that do contain Hg.	NJDEP/DSHW, NJDEP with other states including NEWMOA, & US EPA	Variety of actions must be specified and funded
	Household batteries	Require labeling of button batteries with mercury content. Ban disposal of batteries in trash incinerators (require source separation).	In state purchasing contracts, require that battery vendors take back spent batteries for recycling.	Support and encourage collection and recycling of batteries by households and small businesses (exempt from the Universal Waste Rule).	NJ Treasury. NJDEP/DSHW, County HHW Coordinators, Rutgers	
	Electrical lighting components	Require Conditionally Exempt Small-Quantity Generators to recycle or otherwise appropriately manage discarded fluorescent lamps. Prohibit MSW incineration of spent lamps.	Support classification of discarded fluorescent lamps as universal waste. Adopt state	Promote appropriate management of discarded mercury-containing lamps. Educate	NJ Treasury. NJDEP/DSHW, NJDOT, County HHW Coordinators, Rutgers	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
			procurement policies requiring purchase of low-mercury bulbs. Relamp state buildings with electronic ballasts (to support energy -efficient fluorescent tubes. When setting up or supporting mercury recycling programs, specify recycling technology that reclaims mercury from all parts of the lamp,	waste management contractors and staff about the hazards of handling broken tubes or any materials contaminated with mercury.		

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
			including the glass. Street/exterior lighting: Encourage removal from service of spent lamps only.			
	Fever thermometers	Ban sale of mercury fever thermometers for residential and commercial use.	In state purchasing contracts, specify non-mercury thermometers in applications where digital alternatives are feasible. Fund, support, and encourage local thermometer exchange programs.	Work with small and large retailers to obtain voluntary agreements to stop selling mercury thermometers and to distribute educational materials to customers. Educate public re: hazards of	NJ Treasury, NJDEP/DSHW, NJDOT, County HHW Coordinators, Rutgers	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
				mercury spills from broken thermometers, safe cleanup methods, and importance of turning in mercury thermometers at HHW. Educate physicians re: importance of not giving mercury thermometers to patients.		
	Thermostats	Include thermostats in sales ban of mercury-containing products. Ban mercury-containing thermostats from MSW and require separation/recovery from demolition waste.	Pressure the National Electrical Manufacturers' Association and the Thermometer Recycling	Educate HVAC contractors and plumbers about the Universal Waste Rule and	NJ Treasury, NJDEP/DSHW, NJDOT, County HHW Coordinators, Rutgers	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
			Corp. to promote thermostat recycling effectively. In state purchasing and construction contracts, specify all-digital thermostats and require contractors to remove and recycle thermostats containing mercury.	importance of recycling thermostats containing mercury through TRC. Partner with hardware stores to educate public re: digital thermostats and the importance of HHW disposal of mercury thermostats.		
	Mercury light switches	Include mercury-containing light switches in sales ban of mercury-containing products.	In state demolition and construction contracts, specify non-mercury light switches. Require contractors to	Educate building and demolition contractors about the importance of careful removal and proper	NJ Treasury, NJDEP/DSHW, NJDOT, County HHW Coordinators, Rutgers	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
			remove and recycle switches containing mercury.	disposal of mercury switches. Partner with hardware stores to educate the public about hazards of mercury and importance of recycling old switches and replacing them with non-mercury alternatives.		
Promote energy conservation and renewable energy to reduce use of fossil fuel	Coal, fuel oil, diesel and gasoline combustion			Educate the public about the Hg-pollution prevention advantages of energy conservation	Need to identify lead. Possibilities: NJDEP/NJBPU, Sustainability, Consumer groups	Coordinate with funded GHG gas reduction effort?
Phase out use of mercury containing amalgam for dental fillings. Ensure that state contracts provide equal insurance coverage for non-mercury fillings and consider not covering amalgam fillings.	Dental office waste, sludge, wastewater, crematoria	Yes. (Legislation in other states goes beyond NEWMOA goal of contract assurances and BMP publication.)		Yes	NJDEP/DSHW w. NJDHSS & Dental Assocs., County HHW coordinators, Rutgers	
Phase in use of effective traps		Yes		Yes	NJDEP/DSHW w.	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	**Sources Addressed**	**Legislation required**	**Executive action/ order/department policy required**	**Education/ Outreach**	**Primary Agency for Implementation**	**Implementation/ Funding Status**
to capture mercury from dental offices.					NJDHHS & Dental Associations	
Develop and fund effective intervention strategies and outreach regarding cultural and ceremonial uses of mercury.	Cultural and ritualistic uses			Yes	NJDHSS	
CONTROLS ON DISPOSAL						
Implement programs that result in source separation, recycling and retirement of mercury-containing items, including restrictions on incineration of Hg-containing products.	Sludge; wastewater; air emissions from solid, medical, and hazardous waste management and disposal facilities; indoor emissions from spills	Require appropriate management of discarded mercury-containing items. Require source separation of mercury-containing wastes to be incinerated. Legislation required to address CESQG exemption under Universal Waste Rule: require either transport of intact tubes to landfill, or recycling.	Yes, including development and implementation of contract(s) to recycle or otherwise properly manage spent fluorescent tubes from state office buildings. Increase efficiency of post-combustion emissions controls on MSW incinerators. Support and fund pilot mercury source separation projects.	Yes Encourage source separation for MSW destined for MSW incinerators.	NJ DEP/DSHW, NJDEP, Treasury, w. Other states including County HHW Coordinators, Rutgers, NEWMOA, & USEPA	
Provide incentives to industry to eliminate mercury from products. Examples include government and other motor vehicle fleets, appliances, and computers.	Iron and steel manufacture	Legislation required to ban mercury-containing products from recycling/disposal facilities that are not equipped to control mercury emissions.	Government procurement guidelines to 1) include new vehicles and appliances that do not contain Hg switches; 2) require vendors/ mfgrs to take back items containing Hg; 3) feature low-mercury fl. Tubes; 4) support		NJ DEP/DSHW, NJDEP, NJDOT, Treasury, in coordination w. other states inc. NEWMOA, & USEPA, Scrap metal Assocs., Auto Recycler Assocs.	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
			re-lamping of state buildings.			
EMISSIONS CONTROLS						
Include mercury emissions in the labeling requirements for electricity sold	Coal combustion		Yes	Yes	NJBPU/NJDEP	
As part of a multi-pollutant strategy, develop a national mercury air emission standard for coal combustion.	Coal combustion		Strongly support increased government and public purchase of "green energy." Support USEPA policy.	Yes	USEPA, Elec. producers, interstate assocs., inc. ECOS, OTC, NESCAUM, STAPPA/ALAPCO	
Set a NJ mercury release emission performance standard for iron and steel manufacturers that could be met with a combination of pollution prevention and emission controls; require mercury stack testing with appropriate frequency.	Iron and steel manufacture		Yes		NJDEP/Air Quality Regulation	
Once emissions from aluminum processing facilities are identified (through on-going research project), review inventory and if appropriate, propose emission reduction options.	Aluminum processing facilities	???	???		NJDEP/AQR	Current research project is funded
TRANS-BOUNDARY ACTIONS						
Advocate regional and national source reduction, best management practices, and national standards for mercury controls for key source categories, including energy production and MSW	Air transport leading to NJ air deposition		Continue to work with interstate and national organizations to promote source control and Hg emissions	Yes	USEPA, interstate assocs., inc. ECOS, OTC, NESCAUM, STAPPA/ALAPCO	

III.2.2. Mercury Task Force Priority Reduction Recommendations

Action	Sources Addressed	Legislation required	Executive action/ order/department policy required	Education/ Outreach	Primary Agency for Implementation	Implementation/ Funding Status
incineration.			reductions.			

RESEARCH AND DEVELOPMENT				
Action	**Sources Addressed**	**Executive action/ order/department policy required**	**Lead Implementation Organization**	**Implementation/ Funding Status**
Conduct research and implement where practicable programs to lower the amounts of mercury in products including lamps, measuring and control devices and switches, and other products.	Sludge, wastewater, air emissions from waste management and disposal facilities, indoor emissions	Yes. Support US EPA "Vision 2020" goal of development of fluorescent lamps that do not contain mercury.	?	Variety of actions must be specified and funded
Continue to monitor and report on current pilot studies of options for flue gas control of mercury from coal combustion, further develop instruments for measuring mercury concentrations continuously in flue gas, further develop mercury emission control technologies, and implement full scale demonstration projects between 2001 and 2003.	Coal combustion		US EPA, Electricity producing industries	
Research releases during handling and stabilization of dredged materials , and clarify potential releases from the dredging itself.	Dredged materials		NJ DEP, coordinated with US EPA, NJ Maritime Resources, US Army COE	
Acquire better information on portion of releases to air, water, and land that are oxidized inorganic mercury (Hg^{++}), elemental mercury (Hg^0), and organically-bound mercury.	Most sources		US EPA, other federal and state agencies, electricity producers	
Study comparative cost of source separation and additional MSW incinerator emissions controls.	MSW incineration		DEP	Funding required

E. Source-reduction recommendations organized by type of action.

Reduction recommendations can be categorized by type of action expected to be required to complete the recommendation. These types of action include legislation, regulatory and actions by government under existing authorities, and outreach (by others as well as government and others).

F. State Legislation

The Task Force recommends that the New Jersey Legislature pass appropriate legislation to authorize the following actions:

1. Sales phase-outs and restrictions that:

- Rapidly phase out sales of mercury-containing products for which there are reasonably available alternatives that do not contain mercury, including mercury fever thermometers, switches, thermostats, appliances, and novelty items;
- Rapidly phase out the sale or resale of vehicles that contain mercury in switches or other mercury-containing components;
- Require product labeling showing mercury content, including button batteries and mercury-containing lamps.

2. Waste disposal and source separation requirements that:

- Prohibit mercury-containing products from recycling-disposal facilities that are not equipped to control mercury emissions;
- Prohibit disposal in trash incinerators of potentially mercury-containing material, such as fluorescent tubes, thermostats, and other electrical equipment;
- Require businesses classified as "Conditionally Exempt Small-Quantity Generators" under the Resource Conservation and Recovery Act (RCRA) to recycle or otherwise appropriately manage fluorescent lamps;
- Phase out the use of mercury-containing amalgam for dental fillings;
- Require that dentists install effective traps to capture mercury amalgam and dispose of amalgam appropriately (e.g., not with medical waste to be incinerated).

G. Executive actions/administrative orders/regulatory actions

1. General recommendations

The Task Force recommends that the Governor or, as appropriate, the Commissioner of the Department of Environmental Protection:

- Support regional and national initiatives to reduce mercury emissions from all sources, particularly development by the U.S. Environmental Protection Agency (USEPA) of a national mercury air emission standard for coal combustion;

- Continue to work with interstate and national organizations to promote source control and mercury emissions reductions, including the promotion of the Northeastern Governors' Mercury Action Plan goal of "virtual elimination of the discharge of anthropogenic mercury into the environment…";
- Encourage source reduction, best management practices, and national standards for mercury controls for key source categories, including energy production, iron and steel manufacture, and municipal solid waste (MSW) incineration;
- Support the USEPA "Vision 2020" goal of development of fluorescent lamps that do not contain mercury;
- Provide incentives to industry to eliminate mercury from products;
- Develop a performance standard for mercury emissions control that must be met by recycling/disposal facilities contracted by the State;
- Support classification of discarded fluorescent lamps and vehicle switches as universal wastes under the provisions of RCRA;
- Support and fund pilot mercury source separation projects managed through New Jersey county household hazardous waste programs;
- Initiate and facilitate discussion among regulators, iron and steel manufacturers, auto dismantlers, scrap processors, and auto industry representatives to work out a coordinated plan to eliminate mercury in scrap metal and support a pilot "bounty" program if this stakeholder process endorses one;
- Encourage the removal from service of street lamps/exterior lighting lamps only if they are at the end of their life;
- Fund, support, and encourage local thermometer exchange programs;
- Require that mercury switches in State vehicles be removed or replaced by non-mercury containing switches during vehicle maintenance, and that the mercury be reclaimed and sequestered;
- Promote the purchase of electric power generated from certified green sources, including renewable sources and sources with low or zero mercury emissions.

2. State purchasing/contracting policies

The Task Force recommends that the Governor issue an executive order requiring the Department of the Treasury to adopt State purchasing and service contract guidelines that will accomplish the following and that the Governor take action to encourage the private sector to follow the State's example:

- Require the purchase for State facilities of electric power generated from certified green sources including renewable sources and sources with low or zero mercury emissions;
- Require the purchase for State use of new vehicles and appliances that do not contain mercury switches;
- Require the purchase of low-mercury fluorescent lamps for State facilities;
- Encourage the re-lamping of State buildings with low-mercury lamps and electronic ballasts;

- Require that discarded fluorescent lamps from State and municipal facilities be managed appropriately so as to prevent the release of any contained mercury to the environment;
- Require that State construction/demolition contract language provide for the removal of mercury-containing thermostats and switches from demolition waste, and the appropriate management of any contained mercury before disposal;
- Require the purchase by the State of non-mercury fever thermometers for applications where alternatives are acceptable.

3. Regulatory actions/permitting

The Task Force recommends that the Commissioner of the Department of Environmental Protection:

- Revise the State's air pollution control regulation governing Municipal Solid Waste (MSW) incinerator emissions to increase the required efficiency of post-combustion emissions controls;
- Recommend to the Director of the State Bureau of Public Utilities (BPU) that "portfolio" mercury emissions per electrical energy production be reported to consumers, via labeling, by each retail electricity supplier;
- Revise the State's air pollution control regulations for mercury to set an emission performance standard that can be met with pollution prevention and/or air pollution control devices. The timing of the standard should allow for mercury elimination and separation to be implemented over a reasonable period, with air pollution control devices only required after this period if the pollution prevention measures do not independently achieve the performance standard;
- Propose appropriate emission reduction requirements if the Commissioner deems mercury emissions from aluminum processing facilities to be significant;
- Revise the State's sewage sludge mercury provisions to reflect a phased reduction in mercury levels, and include the New England Governor's Association recommended emission standard for sludge incineration facilities as an alternative to the final sludge concentration goal;
- Adopt state standards if EPA does not, by December 2003, proceed to promulgate and implement effective mercury limits.

4. Incentives for businesses and industry to remove/reclaim mercury from products.

The Task Force recommends that the Governor or, as appropriate, the Commissioner of the Department of Environmental Protection:

- Support programs that provide incentives to auto dismantlers and scrap processors to remove mercury-containing components from products, and to manage the mercury appropriately so as to prevent the release to the environment;
- Strongly encourage the National Electrical Manufacturers' Association and the Thermometer Recycling Corp. (TRC) to promote thermostat recycling efforts;

- Ensure that health insurance contracts available to State employees provide coverage for non-mercury fillings.

H. Education/ Outreach

The Task Force recommends that the Commissioner of the Department of Environmental Protection initiate programs and policies that:

1. General outreach and education

- Inform and educate the public about New Jersey's advocacy positions favoring the virtual elimination of mercury from the State's air, water, and soil;
- Use the county hazardous waste programs to increase public awareness of low-mercury products and available alternatives;
- Educate residents, businesses, and others about the importance of segregating and properly disposing of mercury-containing waste;
- Support and encourage collection and recycling by households and small businesses of accumulated liquid mercury fever thermometers, thermostats, fluorescent lamps, batteries, and other products containing mercury;
- Educate the public about the importance of purchasing certified green power from non-mercury-generating sources.

2. Targeted outreach to businesses

- Educate auto dismantlers, shredders, fleet managers, vehicle service facilities, and other relevant audiences about the importance of removing mercury-containing components from vehicles and appliances before they are processed into scrap;
- Educate heating, ventilation and air conditioning (HVAC) contractors and plumbers about the Universal Waste Rule and the importance of proper management of thermostats containing mercury;
- Educate building and demolition contractors about the importance of careful removal and proper disposal of mercury thermostats and switches;
- Educate waste management contractors and staff about the hazards of handling broken lamps or any other materials contaminated with mercury;
- Partner with hardware stores to educate customers about the availability of digital thermostats and non-mercury light switches, and the importance of disposal of mercury-containing thermostats and switches through household hazardous waste programs, in advance of passage of sales ban legislation;
- Work with small and large retailers, in advance of passage of sales ban legislation, to obtain voluntary agreements to stop selling mercury thermometers and to distribute educational materials to customers.

3. Targeted outreach to medical professionals and their patients

- Educate physicians about the importance of not using mercury thermometers and about encouraging their patients not to use them;
- Educate dentists about the available alternatives to mercury amalgam, the importance of effective amalgam traps and proper amalgam disposal.

4. Targeted outreach addressing cultural uses of mercury

- Develop and fund effective intervention strategies to reduce the cultural uses of mercury;
- Prepare and disseminate culturally sensitive education materials in the appropriate languages;
- Work with community and religious leaders to identify and promote acceptable alternatives to the cultural use of mercury.

Volume III, Chapter 3: Specific Source Descriptions

Introduction

The following specific sources and source categories are discussed in detail in this chapter.

FUEL COMBUSTION AND ENERGY
Coal Combustion
Fuel oil combustion: distillate (including #2 fuel oil, diesel fuel, kerosene, and jet fuel)
Fuel oil combustion: residual (including #4 and #6 fuel oil)
Gasoline combustion
Natural gas combustion
Petroleum refining
Wood combustion

PRODUCTS AS A MERCURY SOURCE
Cultural uses
Fluorescent lamps
Industrial and commercial sources not elsewhere listed
Iron and steel manufacturing and ferrous scrap processing
Mercury-containing products in general use
Non-ferrous metals, including aluminum and aluminum scrap processing
Painted surfaces

HEALTH, EDUCATION, AND RESEARCH FACILITIES
Crematoria
Dental office waste
Laboratories
Medical waste incineration
Medical waste, not incinerated

WASTE AS A MERCURY SOURCE
Dredged materials management
Hazardous waste incineration
Hazardous waste sites
Landfill gas
Landfill leachate
Municipal solid waste combustion
Municipal solid waste deposited in landfills
Sludge management: incineration, land application, and disposal
Soils, contaminated: thermal treatment
Wastewater

NATURALLY OCCURRING EMISSIONS

APPENDIX A, EVALUATION OF CONTROL OPTIONS FOR THREE SOURCE CATEGORIES

APPENDIX B, CALCULATION OF MERCURY RELEASES FROM PRODUCTS IN USE AND DURING THE WASTE DISPOSAL PROCESS (NOT INCLUDING FLUORESCENT TUBES)

APPENDIX C, CALCULATION OF POTENTIAL MERCURY AIR EMISSIONS FROM THE LAND DISPOSAL OF DREDGED MATERIALS

Each source-specific discussion is a product of an iterative process carried out by the Sources Subcommittee. In this process, Subcommittee volunteers prepared the initial version of each write-up. A second Subcommittee member, not a representative of an industry associated with the source, then reviewed and revised the initial version. All available resources were used for information, including NJDEP authorized stack tests and specific sampling efforts. Subsequent reviews and revisions were carried out as necessary based on discussions at Subcommittee meetings and conference calls. References and details are in a spreadsheet available from the NJDEP Division of Science, Research, and Technology.[1]

---

[1] Contact Michael Aucott, NJDEP, DSRT, PO Box 409, Trenton, NJ 08625-0409, 609-984-6070, maucott@dep.state.nj.us.

Coal Combustion

Identification and Description of Source

As of December, 2000 , there are 10 coal-fired electric generating units in New Jersey. Three are operated by an investor-owed utility (Conectiv), one by a municipal utility (City of Vineland), and three each by a wholesale generator (PSEG Power) and an independent power producer (PG&E Generating). Since Conectiv has committed to selling its units, it is expected that in early 2001, none of the 10 coal-fired electric generating units in New Jersey will be owned by investor-owned utilities. However, all 10 facilities are expected to continue to operate in New Jersey. Increased costs in natural gas and other fuel oils may in fact increase coal fired electricity generation in New Jersey.

Quantity and Estimated Uncertainty

NJDEP stack tests performed from 1994 through 1997 indicate that these units collectively emit to the air about 700 ± 300 lb. of mercury annually. However, recent nationwide data from the USEPA, based on reported plant fuel use and mercury tests at other plants made available pursuant to EPA's 1999 information request, estimate that New Jersey coal-burning utilities release 200 lbs. of mercury annually. EPA reportedly based its estimates on: measurements of the mercury content of coals sampled at approximately every 6th shipment; the actual consumption of coal at the plants; and the calculated mercury capture rates based on type of plant and control devices at each unit. Stack test data at a number of plants around the country were used to develop the estimates of the capture rates for certain types of plant and control device. The NJDEP stack test data are used as the basis for the emission estimate from this sector because the EPA emissions factors were not developed based on data from New Jersey plants.

Mercury emissions also occur from out-of-state combustion of coal associated with the generation of electricity used in New Jersey. The quantity of these emissions can be estimated from energy use data. Most electricity imported to New Jersey flows through the PJM Interconnection power control area (PJM). The generation resource mix of the PJM in 1998 was 47% coal.[2] In 1999, in-state coal combustion supplied approximately 70 quadrillion Btus of energy to the generation of electricity used in NJ, whereas energy consumed in the generation of imported electricity totaled approximately 300 quadrillion Btus.[3] Assuming that 47% of the imported electricity was generated with coal combustion, approximately 150 quadrillion Btus were released by out-of-state coal combustion in the generation of electricity used in New Jersey. With the assumption that associated mercury emissions are proportional, perhaps 1500 pounds of mercury are released from out-of-state coal combustion to generate electricity imported to New Jersey. If these emissions are added to the estimated 700 ± 300 lbs./yr. noted above, the total

---

[2] USEPA, 2001, Emission and Generation Resource Integrated Database, Version 2.0, USEPA Office of Atmospheric Programs, Washington, DC, September, 2001.

[3] US Department of Energy, Energy Information Administration (USDOE/EIA), 2001, NJ State Energy Data Report, data file, downloaded from http://www.eia.doe.gov/pub/state.data/data, 10/29/99; new data rec'd 5/10/01 w. e-mail to M. Aucott, NJDEP, from Julia Hutchins, DOE/EIA.

mercury emissions from coal combustion associated with New Jersey electricity consumption is approximately 2200 ± 1000 pounds per year.

Sectors Affected

In terms of electricity generation and use, supply side refers to the production of electricity and demand side refers to the use of electricity. On the supply side, the sectors affected would be the electric power producers. On the demand side, the sectors affected are the commercial, residential and industrial consumers of electricity.

Receiving Media

The initial receiving medium is the air. As noted below, emissions are primarily elemental and oxidized gaseous species. Elemental mercury tends to circulate around the world, and ultimately is deposited on the land and water. Oxidized mercury tends to be deposited (in rainfall, snowfall, or as dry deposition) within a relatively short distance of the source.

Chemical Species

This mercury is primarily in the vapor phase, either as the free element (Hg^0) or in an oxidized form (Hg^{++}).

Reduction Options and Associated Costs and Impediments

Source reduction options include generation efficiency improvements, coal cleaning, fuel switching, and substitution with renewable energy. On the demand side, source reduction options include increased energy efficiency of devices that use electricity[4] and substitution of non-electricity-powered devices. Emission control options include carbon (or other sorbent) injection and wet scrubbing (FGD).

Source Reduction Options

Supply Side

Coal cleaning is a process of purification performed on raw coal to obtain a high-energy, low-sulfur, low-moisture and minimum-ash final product. Various cleaning methods are used individually or in combination with one another, depending on the characteristics of the coal and the degree of cleaning needed to meet the specifications. These methods include crushing, size sorting, density sorting (flat/sink cleaning) and froth flotation. Optimization of the coal cleaning process relies on the supplier's criteria for meeting the overall specifications. The supplier is concerned with maximizing his yield, expressed as a percentage of raw coal mined, with minimal treatment.

---

[4] For example, replacing single speed electric motors with variable speed motors to match the load, replacing inefficient incandescent lighting with high efficiency fluorescent lights, and replacing inefficient appliances with more efficient models.

Coal cleaning is already performed on the coal burned in 8 of the 10 New Jersey power plants. Deep cleaning, which requires a somewhat more sophisticated approach than conventional cleaning, and is thus more expensive, may be able to reduce the mercury content on a pounds per Btu basis. This technology has not been fully developed, and its efficacy is highly dependent on the original coal. Some coals experience an increase in mercury content (on a pounds per Btu basis) as a result of deep cleaning. It is estimated that additional cleaning of Central Appalachian coals to 2% ash content would add $6/ton to their cost, increasing coal cost by about a third. Such deep cleaning has not yet been deployed commercially.

Any effort that will reduce energy usage including increased production efficiency will have the collateral effect of lessening the environmental impact of this category. Switching to other types of fuel that have a lower mercury content would also lead to reductions of emissions from the coal combustion source.

Another supply side option is the replacement of fossil fuel electricity generation with a renewable energy source that has low or no mercury emissions. Class I renewable energy sources are defined in the Electric Discount and Energy Competition Act (Act) as photovoltaic, wind, wave, or tidal power, solar thermal electric, fuel cells, or geothermal. Class II renewable energy sources are municipal solid waste incinerators that generate electricity and hydroelectric electricity generation. Nuclear energy is not defined as a renewable source. As required in the Act, all energy suppliers selling electricity in New Jersey must comply with a Renewable Portfolio Standard (RPS). This means that a portion of the electricity in each suppliers' overall electricity portfolio must be generated from Class I or II renewable energy. The initial renewable energy percentage requirement for Class I is 0.5 %. The percentage increases to 6.5% in 2012 of which 2.5% is to be from Class I or Class II renewables and 4% is from Class I. Currently, New Jersey uses 68 million megawatt hours (million Mwh) of electricity yearly. Per the requirements of the Act, in 2012 approximately 2.7 million Mwh must be supplied by Class I renewables and 1.7 million Mwh must be supplied by Class I or II renewables.

Demand Side

A cost-effective tool for reducing overall emissions is demand side energy efficiency improvements. Increasing the efficiency of devices that use electricity could reduce the amount of coal burned, thereby reducing the amount of mercury emissions. In addition, demand side energy efficiency would also reduce the emissions of CO_2, SO_2, NO_X, particulates and other trace metals.

The amount of reduction in mercury emissions achieved through demand side energy efficiency will vary depending on the fuel used to generate the electricity. U. S. average electricity generation is 52% coal, 18% nuclear, 14% gas, 13% renewable (82% hydro, 13% biomass, 5% other renewables), and 3% oil (1997).[5] In New Jersey the fuel used for electricity generation are

---

[5] USDOE, 1997, *Energy Information Agency Electric Power Annual 1997, STAPPA/ALAPCO Reducing Greenhouse Gases - A Menu of Harmonizing Options Final Report* October 1997

58% nuclear, 28% coal, 12% gas and 2% oil (*1997)*.[6] Demand side energy efficiency improvements that displace electricity generated through nuclear power or non-biomass renewable energy sources will not provide mercury emission reductions since these sources do not emit mercury. Demand side energy efficiency improvements that displace natural gas and fuel oils will result in very small mercury emission reductions. Demand side energy efficiency improvements will result in substantial mercury emissions reductions from utilities that rely heavily on coal.

This issue is compounded by the fact that New Jersey does not generate in-state, all the electricity it consumes. Of the 68 million MWh of electricity used in New Jersey each year, 21% is imported into the state through the PJM pool from out-of-state sources *(1998)* [7]. With restructuring of the energy markets in New Jersey as a result of the New Jersey Electric Discount and Energy Competition Act, to provide for open market competition, it is expected that the importation of electricity will increase.[8] There is no current way to ensure that a kilowatt reduction resulting from demand side energy efficiency will have a corresponding reduction in mercury emissions.

However, there are ways to increase the effectiveness of energy efficiency strategies to reduce mercury emissions. They include a two-prong approach. One is implementing an outreach and education program with the objective of promoting an understanding by electricity users of the overall environmental impacts of the electricity they use, including mercury emissions. This program would focus on the overall environmental impacts of the various sources and fuels used to generate electricity including fossil fuel, nuclear and renewables. This would encourage users to consider and select electricity from renewable sources. The other is to develop a national energy policy with a program that interconnects the various goals and objectives of the individual state programs for energy efficiency and renewable energy programs.

If electricity users understood the overall environmental impacts of the various fuels that made up their energy supply including coal, nuclear, natural gas, oil, hydro, biomass wind, and photovoltaic; and the emissions levels of these fuel mixes (including CO_2, NO_x, SO_2 and Hg), they could then make the informed choice to use electricity generated by a low or no mercury fuel source. This energy choice would be similar to the choice consumers now make to buy low fat or no fat food product based on the nutritional fact labels on food products.

As a result of the recently enacted Electric Discount and Energy Competition Act N.J.S.A. 48:3-49 et seq. (P.L. 1999 c. 23), consumers of electricity have a choice of the electric supplier that generates their energy. In order to ensure that the choice of the electric supplier is not made solely on the cost of that service, the Act requires that the electric suppliers or basic generation service providers disclose the environmental characteristics of the energy purchased by the customer including the following:

---

[6] *USEPA E-GRID electric database for New Jersey 1998*

[7] *PJM -GRID electric database for New Jersey 1998*

[8] *USDOE - Energy Information Agency Electric Power Annual 1997*

1. The fuel mix including fossil, nuclear and renewable sources;
2. The emissions in pounds per MWh for CO_2, SO_2, and NO_x; and
3. The electricity supplier's support of energy efficiency as reflected by the retirement of discrete emissions reduction credits.

This label of the environmental characteristics of the energy purchased does not currently include mercury. The Act allows the New Jersey Board of Public Utilities (BPU) to add other pollutants to the disclosure rule, if determined to pose an environmental or health hazard.

The disclosure rules are in effect as interim standards until March 2002 unless final standards are adopted by the BPU prior to that time. The BPU, in consultation with the NJDEP, may amend or readopt the current interim regulations in accordance with the Administrative Procedures Act at NJSA 52:14B-1 et seq. The department as part of its environmental consultative role to the BPU, can make a finding to the BPU that mercury poses an environmental and health hazard. Further, as part of the environmental advice, the department can recommend to the BPU to include mercury as a new pollutant on the disclosure label, within its rule-making process.

Control Options

Particulate control systems are not effective for pollutants that are in the vapor phase. They do not efficiently capture gaseous pollutants that are carried with the combustion fine particles. However, sorbents can be used to adsorb the vapor-phase metals onto solid particles (the sorbent) large enough to be collected in the particulate control system.

The primary sorbent used for air toxics control is activated carbon. Activated carbon is injected in powder form into the flue gas upstream of the particulate control device. After injection into the flue gas and adsorption of mercury and other contaminants, the activated carbon is captured in the particulate control device. Activated carbon has been used in municipal waste combustors (MWC) and medical waste incinerators (MWI) with success. However, the concentration of the contaminants in the flue gas of those facilities is significantly higher than in the flue gas streams of coal-fired boilers. The mercury concentration in uncontrolled flue gas of many coal-fired boilers is in the same range as the exit concentration in controlled MWCs and MWIs.

Laboratory-scale and slipstream tests of activated carbon have been conducted on coal-fired boiler flue gas. These tests, having been conducted with various types of coal, greatly differing flue gas conditions and compositions, varying amounts and speciation of mercury, and differing rates of activated carbon injection, show great promise. Mercury removal efficiencies have varied from about 30% to about 90%. Generally speaking, mercury removal is enhanced by higher injection rates of activated carbon and lower flue gas temperatures.

According to EPA, efficient distribution of the activated carbon in the flue gas is also important. The amount of sorbent needed to achieve a specific level of mercury removal will vary depending on the fuel being burned, the amount of chloride present in the fuel and the type of particulate matter control device. At a given sorbent feed rate, a fabric filter provides more mercury control than an electrostatic precipitator (ESP) because of the additional adsorption that occurs on the bags of the fabric filter and due to the increased gas contact time. As a result, an ESP-equipped facility may required a higher carbon feed rate to achieve the same level of control as a fabric-filter-equipped facility.

Activated carbon feed rates may range from 1,000 to 100,000 pounds per pound of mercury removed and may produce 90% removal. Depending on the specific conditions assumed, EPA has quoted in its Mercury Study Report to Congress[9] cost estimates from $5,000 to $70,000 per pound of mercury removed. Other costs may be added to the process, such as disposal costs, etc. As the cost of sorbents decline, so do the costs per pound of mercury captured. However, the cost of the sorbent must be weighed against the amount of sorbent needed. Some lower-per-pound cost sorbents may require higher sorbent use, thereby eliminating some of the saving.

Generally, the lower the fraction of the mercury which is present in the flue gas in the elemental form, the higher the total mercury removal efficiency. This is because mercury compounds (Hg^{+II}) are more easily removed than elemental mercury (Hg^0). The presence of chloride in the coal tends to increase the fraction of Hg^{+II} in the flue gas. The presence of SO_2 tends to increase the fraction of Hg^0, thereby reducing the ability of activated carbon to capture mercury. There is some indication that total mercury removal increases with the increase of unburned carbon (loss on ignition) in the fly ash.

The injection of activated carbon into a utility flue gas stream could have a significant impact on the quantity and quality of particulate matter requiring disposal. EPA has estimated that a 100-MW coal-fired boiler with an ESP could potentially inject about 490 tons of activated carbon per year, which would be about 2.5% of the total ash (20,000tons/yr).[10] It is believed that ash collected during carbon injection could be landfilled if not salable. While further tests of coal ash with carbon would be useful, municipal solid waste ash tests have demonstrated that the mercury collected on the activated carbon is stable at temperatures typical of landfills and is not re-emitted to the atmosphere.[11,12,13]

---

[9] USEPA, 1997, *Mercury Study Report to Congress, Volume VIII: An Evaluation of Mercury Control Technologies and Costs*, EPA-452/R-97-010, p. ES-4

[10] USEPA, 1997, *Mercury Study Report to Congress, Volume VIII: An Evaluation of Mercury Control Technologies and Costs*, EPA-452/R-97-010, p. 2-28.

[11] Electric Power Research Institute (EPRI), 1999, *The Stability of Mercury Captured on Sorbent Surfaces*, EPRI, Palo Alto, CA, TE-113926, October 1999.

[12] U.S. Department of Energy, 1999, *Mercury Stability in the Environment*, Final Topical Report, DOE Cooperative Agreement No. DE-FC26-98FT40320, Task 1.2, July 1999 (available from the Federal Energy Technology Center)

[13] Brown, Thomas D., Smith, Dennis N., Hargis, Richard A. Jr., and O'Dowd, William J., 1999, U.S. Department of Energy, Federal Energy Technology Center, "Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate," *Journal of the Air & Waste Management Association*, June 1999.

Chemically impregnated activated carbon can be used to enhance mercury removal over the more traditional activated carbon. With chemically impregnated activated carbon, the mercury reacts with the chemical that is bound to the carbon, and the compound, as before, is removed by the particulate control device. Chemically impregnated carbons require smaller rates of carbon injection than does activated carbon for equivalent mercury removals. The required carbon-to-mercury mass ratio may be reduced by a factor of from 3 to 10 with the chemically impregnated carbons. However, the cost per mass unit of impregnated activated carbon may be significantly greater than that of unmodified activated carbon.

Impregnated activated carbons have been tested on European MWCs and MWIs. Some of the impregnated activated carbons that are available commercially were developed for other applications and cannot tolerate the high temperatures encountered in utility flue gas streams. Typical impregnants for activated carbon are chloride, sulfur, iodide, and silver. Another commercially available material, Sorbalit^{TM}, is a mixture of lime with additives and 3-5% activated carbon.

A number of more novel sorbents are being investigated at the laboratory level. These include activated carbon impregnated with recycled silver from waste photographic material and sulfur-impregnated activated carbon derived from waste tires. At the other (high) end of the cost scale, gold dispersed on either activated carbon or alumina is being evaluated.

In order to minimize the total amount of toxic waste in the process, non-toxic food additives are being investigated, with some success, as candidate sorbents for mercury removal from utility flue gas streams.

Zeolites comprise another category of non-toxic sorbent. There are naturally occurring mineral zeolites, in addition to commercially available synthetic zeolites. Fixed blends of these substances have been proposed for variety of mercury control applications, but none have been developed specifically for control of mercury in coal flue gas. Zeolites have not been proven effective sorbents for mercury control. However, it may be possible to manufacture specifically tailored zeolites for this purpose. Control cost will depend on effectiveness of tailored zeolite in removing mercury. A highly effective zeolite has the potential to require much less sorbent than various activated carbons, and would not affect ash quality.

PSE&G has hosted pilot scale demonstrations of mercury removal technologies at its Hudson and Mercer plants with good success. The technology piloted at Hudson is the EPRI TOXECON procedure, in which activated carbon or a combination of activated carbon and an alkaline material, e.g., lime, is sprayed into the flue gas upstream of a small pulse-jet fabric filter (COHPAC). The pilot results indicated that very high (up to 90%) mercury removal could be achieved under certain conditions. At Mercer, Environmental Elements Corporation produced reasonably good mercury removals with a circulating fluidized bed ash utilizing injected activated carbon.

Water injection into the flue gas at the entrance to a cold-side electrostatic precipitator might cause sufficient cooling of the stream to allow more mercury to be collected with or without sorbent injection.

At Logan (PG&E Generating), where a spray dryer is used to lower the temperature of the flue gas, the temperature of the flue gas entering the baghouse is near the condensation point for mercury. This lower temperature apparently causes a significant portion of the mercury entering the particulate control device to be particulate-bound, and this mercury is therefore captured by the particulate control system. Also, the fly ash removed in the baghouse, some of which adheres to the bag surface, contains significant unburned carbon that may act as a sorbent for mercury much the way activated carbon does. There is also some indication that the catalyst employed in the Selective Catalytic Reduction system for NO_x removal may cause Hg^0 to transform to Hg^{+II}, and thereby improve mercury removal.

Research, Development, and Monitoring Options

Monitoring instrumentation is being developed to provide real time stack gas analysis for mercury. Tests conducted by EPA and DOE indicate that these instruments are not yet ready for commercial installation in the field.[14] The instruments tested were capable of measuring mercury concentrations with a precision of ± 20%.

PSE&G has sponsored a number of pilot-scale and full-scale demonstrations of continuous emissions monitoring (CEM) for mercury at its Mercer facility. One of the full-scale CEM technologies that was presented to the Mercury Task Force and evaluated by NJDEP was the Edison Electric Institute (EEI) technology. The EEI CEM technology is based on plasma emission spectroscopy and demonstrated good sensitivity in the 0.1 $\mu g/m^3$ range with cost, as represented by EEI, comparable to periodic stack testing for mercury.

Monitoring efforts at present consist of compliance with the EPA Information Collection Request, which required in 1999 the determination of the mercury and chlorine content of at least three coal shipments per month to each coal-fired generating station in the country. The results are expected to provide a reasonable first approximation of the actual amount of mercury going into the coal-fired utility boilers in the United States. Also, representative samples of coal-fired units across the country were selected by EPA to conduct stack sampling and analysis to determine speciation and emission rate of mercury. Those results are expected to provide a reasonable first approximation of the actual amount of mercury being emitted from coal-fired utility boilers in the United States, as well as identify mercury removal effectiveness of existing power plant equipment and control apparatus.

Outreach and educational options

Supply Side

---

[14] USEPA, 2000, Workshop on Source Emission and Ambient Air Monitoring of Mercury, September 13-14, 1999, Bloomington, MN, EPA /625/R-00/002, June 2000, p. 72-74.

Starting for reporting year 2000, the USEPA lowered the reporting threshold for mercury for the Toxic Release Inventory (TRI) to 10 pounds per year. Also, electric generating plants are required to report releases for TRI starting with reporting year 1998. Consequently, annual data for mercury emissions from electric power production, as well as other emitters whose emissions were not reported because these emitters were previously below the threshold, will be available in 2001. The mercury data for power production as well as other reporting sources should be evaluated and presented to the public annually, with 5-year trends provided in the future.

Demand Side

The information on electricity generation sources and emission rates for CO_2, SO_2 and NO_x is currently available on the disclosure labels from all retail energy suppliers selling to consumers in New Jersey. For new suppliers doing business in New Jersey, this information was based on a default label for the year 2000, but is based on actual emissions and generation sources in 2001. For existing suppliers, this information was based on historical values. The department should, in consultation with the BPU and other state agencies, develop and implement an effective outreach and education program to promote the purchase of 'green power' by the residential, commercial and industrial sectors. 'Green power' is defined as electricity generated from a set percentage of Class I or Class II renewable energies or that is generated with overall environmental impacts below an established environmental baseline.

This demand side outreach and education program to the public to promote the purchase of green power should include a component on low and no mercury electricity sources. The outreach and education program should be developed in consultation with the utilities and energy services contractors (ESCOs), and incorporated with energy efficiency programs for the residential, commercial, industrial and institutional/government sectors promoting strategies for energy conservation and innovative technology.

In January 2000 the NJDEP released its Sustainability - Greenhouse Gas Action Plan. The NJDEP Greenhouse Gas (GHG) Action Plan established a goal to reduce GHG emissions in NJ by 3.5% below the 1990 level by 2005. This will require a 20.5 million metric ton of CO_2 equivalent reduction in projected CO_2 levels across all sectors. The GHG Action Plan evaluated 'no-regrets' strategies that could reasonably be advanced to reach the Action Plan's short-term goal. A 'no- regrets' strategy is defined as a specific measure that is currently commercially available with a simple payback period less than 4 years. The GHG Action Plan strategies include increased use of energy conservation, innovative technology, pollution prevention, recycling, and open space management. It is anticipated that New Jersey and the six other states participating in the Technology Acceptance and Reciprocity Partnership (TARP) sponsored by ECOS, will begin an initiative shortly to develop common protocols to combat climate change, expanding and coordinating the New Jersey initiated effort.

Many of these same strategies should also reduce the emissions of mercury. GHG emission reduction specific measures within each strategy and sector are listed in Appendix A. A component of the GHG Action Plan is the development and implementation of an effective outreach and education program to reduce GHG emission across all sectors utilizing the GHG reduction strategies. An effective mercury reduction strategy would link the mercury energy efficiency and renewable energy outreach and education strategies to the GHG outreach and educational strategies.

As a result of the recently enacted Electric Discount and Energy Competition Act NJSA 48:3-49 et seq. (P.L. 1999 c. 23) there is established a societal benefits charge on the use of electricity in New Jersey. This charge, paid for by the New Jersey users of electricity, helps to fund several programs in New Jersey which have an overall societal benefit. One is subsidizing the energy purchase by consumers with low incomes. Another is the clean up of existing manufactured gas plant contaminated sites across New Jersey. Another is the subsidizing of programs that advance the market transformation in the use of energy efficiency and Class I renewable energy programs that have environmental benefits over and above the current demand side management programs and Class I renewable energy technologies. The energy efficiency and renewable energy fund of the societal benefits charge program will aid in the buy down of the higher initial capital cost of energy efficiency and renewable energies. This fund will greatly aid in meeting the NJDEP GHG emission reduction goal and other air emissions, including reducing mercury emission from energy use. The outreach and education program for mercury reductions should be considered for the societal benefits charge program for energy efficiency and renewable energy funding currently under development by the BPU in consultation with the NJDEP.

It is clear that New Jersey cannot achieve the goals of energy efficiency and renewable energy market transformation to reduce GHG or mercury emissions alone. Twenty-four (24) states have implemented energy restructuring programs. Of these programs, twelve (12) states have system or societal benefits charge programs for energy efficiency and renewable energy funding, some states have disclosure or labeling provisions and some states have Renewable Portfolio Standards. While reducing energy use and reducing mercury emissions are not proportional, reducing energy use will, in most cases, reduce mercury emissions.

The national state utility regulators, the national state environmental regulators, and the national state energy regulators should be encouraged to develop reciprocal interstate programs to establish nationally consistent energy efficiency and renewable energy goals to reduce mercury and CO_2, as well as SO_2 and NO_x. Linking separate state programs together begins to insure that a kilowatt reduction resulting from energy efficiency could have a corresponding reduction in mercury emissions.

Recommendations

The Task Force encourages the development of mercury emission source reduction options and control technologies for coal-fired plants, and encourages the Department of Environmental Protection to work to obtain federal and interstate support to demonstrate such technologies and source reduction options at New Jersey facilities. Once control technologies have been demonstrated, the task force recommends that appropriate emission limits be established for coal-fired plants.

The Task Force supports a comprehensive National Energy Policy, and recommends that New Jersey legislators and policy makers spearhead an effort to embody principles and practices as delineated in this section.

Specific Recommendations

1. The Department should promote energy efficiency with measures consistent with the NJDEP Greenhouse Gas Sustainability Action Plan. This promotion should include implementation of the outreach and education component of the New Jersey Sustainability GHG Action Plan and should expand this program to include the potential mercury emission reductions from the GHG emission reduction strategies.

2. The Department should promote the increased use of electric power from certified green sources including renewable sources and sources with low or zero mercury emissions. The GHG strategies of energy conservation and innovative technologies that promote demand side energy efficiency and supply side renewable energy should be linked to mercury emission reduction outreach and education programs.

3. New Jersey should require environmental information disclosure of mercury emissions per kilowatt-hour from all providers selling electricity in New Jersey consistent with The New Jersey Electric Discount and Energy Competition Act (EDECA) of 1999 (N.J.S.A. 48: 38). The Department, as part of its environmental consultative role to the BPU, should make a finding to the BPU that mercury poses an environmental and health hazard. Further, as part of the environmental advice, the Department should recommend to the BPU to include mercury as a new pollutant on the disclosure label, within its rule-making process when adequate data is available.

4. New Jersey should urge the US Environmental Protection Agency (EPA) to rapidly develop and implement stringent limits on mercury emissions from coal combustion. These standards should include output-based performance limits (mg/MW-hr), which are applied to individual coal-fired power plants, in addition to national caps (tons/year), which are applied to the electric generation source category as a whole. A discussion of potential standards is included as Appendix A, Evaluation of Control Options for Three Source Categories.

5. New Jersey should adopt State standards for coal combustion, if by December 2003 EPA does not proceed to promulgate and implement effective mercury limits on coal combustion.

6. Mercury in coal and mercury emission data generated by the EPA Information Collection Request and Toxics Release Inventory Data should be evaluated. Data should be converted to units of mass of mercury emitted per amount of energy production (i.e., mg/MW hr) for each power plant.

7. Mercury in coal and mercury emission data from coal-fired boilers should continue to be collected by the USEPA on a periodic basis. The mercury data reported pursuant to the TRI requirements for power production as well as other sources should be reviewed as well.

8. Full-scale demonstration projects should be implemented in the 2001 to 2003 timeframe, and experience with these projects should be considered in the establishment of standards.

9. Final compliance should be required in the 2007 to 2010 timeframe to enable coordination with other air pollution control measures also being required.

10. Measures should be established to ensure that the handling, storage, disposal and use of mercury containing ash and other by-products from mercury emission reduction technologies will not allow mercury reentry into the environment.

11. Consistent with the requirements of NJSA 48:3-49 [15], mercury portfolio standards should be established to encourage the use and development of electric generating sources with little or no mercury emissions. Such standards should be expressed in terms of mass of mercury emissions per MW hr of electricity supplied and should apply to the total amount of electricity sold by each retail supplier of electricity to all of its New Jersey customers.

12. New Jersey should work with interstate agencies to assist in the development of federal multi-pollutant legislation that limits mercury emissions. Mercury emissions should be reduced in conjunction with on-going measures to reduce other air pollutants. The State should initiate and foster a partnership between the PJM states to establish a regional mercury emissions portfolio standard. In addition, New Jersey should initiate and foster a partnership between the states, through its leadership role in national energy and environmental organizations including NARUC, NASEO, ECOS, STAPPA and OTC to evaluate the establishment of a national mercury emissions portfolio. This recommendation, to be effective, will require additional measures to ensure that the flow of electricity from low or non mercury-emitting generating sources is correctly attributed to these sources. A system needs to be implemented that adequately monitors the sources of the low or non mercury-emitting electricity, tracking it appropriately to the consumer of that electricity to ensure no double counting and in essence verifies the disclosure label.

---

[15] The New Jersey Electric Discount and Energy Competition Act (EDECA) of 1999 (N.J.S.A. 48: 38 (c)(1), is clear that an emissions portfolio standard (EPS) for any pollutant can be implemented only if: Either two other states in the PJM grid, in addition to New Jersey, comprising 40% load in the PJM region, implement an EPS; or, upon a finding that the standard is necessary as part of a plan to enable the State to meet federal CAA or State ambient air quality standards. This finding requires notice and public comment. Currently, (12/2000) no other state in the PJM grid is pursuing an EPS for any pollutant. If New Jersey pursues the second option, the NJDEP will need to develop an air quality plan that includes the mercury portfolio standard recommendation, and hold public hearings before endorsing this strategy. A public case has to be made that shows this course of action is necessary to meet environmental and health goals, and that the fiscal and other impacts are reasonable.

13. The Department, in consultation with the BPU and other state agencies, should develop and implement an effective outreach and education program to promote the purchase of green power. This program should include a component on low- and zero-mercury electricity sources. The Task Force recommends that the NJDEP recommend to the BPU that this program should also be considered for the societal benefits charge program for energy efficiency and renewable energy funding currently under development by the BPU in consultation with the Department.

Fuel Oil Combustion: Distillate (Including #2 Fuel Oil, Diesel Fuel, Kerosene, and Jet Fuel)

Identification and Description of Source

Distillate fuels include jet fuels, diesel fuels, heating oil, and kerosene. In New Jersey, the consumption of heating oils ranks second only to gasoline in refinery product volume.[16] All distillate fuels are blends of the products and byproducts produced in petroleum refinery operating units. These blends are made to a performance specification based on their end use and not on a percentage of various hydrocarbon molecules present. A key specification on all petroleum products is its boiling range. Jet fuels have a boiling range of between 350°F and 550° F for commercial jets and 150°F and 550°F for military jets. Automotive and truck diesel fuels will have a boiling range between 350° F and 650° F. Railroad diesel fuels are the largest single market for diesel fuels and have a slightly higher boiling range than automotive diesel, which is 700° F. Heating oil and kerosene have a boiling range similar to automotive diesel.

Mercury is thought to exist as a contaminant in all distillate fuels. It is assumed that all mercury present in distillate fuels will be released into the atmosphere during the combustion process.

Quantity and Estimated Uncertainty

No testing has been performed to quantify the total emissions from this source in the state of New Jersey. Mass balance calculations have been used to estimate the quantity released from this source. According to the U.S. Department of Energy, 36,317,000 barrels of distillate oil, which is approximately 1.07×10^{10} pounds and 211.5 trillion Btu, were consumed in New Jersey in 1997, the most recent year for which figures are available. The USDOE also reported that 38,738,000 barrels of jet fuel and 1,701,000 barrels of kerosene were consumed in the state in the same year.[17] The jet fuel combustion quantity, however, represents total jet fuel sold in the state, not which is consumed or produced in the state. Much of this jet fuel would be combusted by aircraft in flight throughout the globe.

The USEPA has used a factor of 7.2 pounds mercury emission per 10^{12} Btu of distillate oil combusted.[18] Based on this emission factor, which translates to nearly 140 ppb,[19] and the quantity of distillate consumed in New Jersey as noted above, about 1500 pounds of mercury would be released by the combustion of distillate in New Jersey. This figure does not include the combustion of jet fuel. In the same report referenced above, the USEPA used an emission factor of 6.8 lbs. per 10^{12} Btu for residual oil, and calculated, based on different fuel consumption figures, that the total combustion of residual and distillate oil in New Jersey released approximately 0.5 tons of mercury per year.

---

[16]. Morris, Robert, Coastal Corporation, personal communication, 2/16/00.

[17]. USDOE, 1997, State Energy Data Report for New Jersey, U.S. Department of Energy, Energy Information Administration, downloaded from http:/www.eia.doe.gov/1pub/state.data/data, December, 1999.

[18]. USEPA, 1997, Mercury Study Report to Congress, Volume II; An Inventory of Anthropogenic Mercury Emissions in the United States, EPA-452/R-97-004, December, 1997.

[19]. 10^{12} Btu of distillate equates to about 5×10^7 pounds. $7.2/5 \times 10^7$ equates to approximately 140 ppb.

Based on recent data assembled by the New Jersey Mercury Task Force, the EPA estimates noted above are unrealistically high. As with other analyses of mercury content of fuels, values reported in the literature based on studies that pre-date the use of ultra-clean laboratory techniques are considered suspect. Ultra-clean techniques, essential for accurate analyses of media containing low levels of mercury, did not become widely used until around 1990; some analytical laboratories still do not use these techniques. Recent analyses of the mercury content of distillate fuels, including diesel oils and kerosene (similar to jet fuel), have shown consistently low values, in the range of 1 ppb.[20],[21]

The mean of values reported in the recent studies was determined to be 0.5 ppb. Multiplying this by the estimated consumption of distillate (not including jet fuel) in New Jersey yields an estimated emission from this source of approximately 5 pounds per year. The inclusion of jet fuel, assuming it has a similar concentration adds another approximately 5 pounds to the total, even if it is assumed that all jet fuel sold in New Jersey is consumed in New Jersey.[22] The overall estimate from combustion of distillate fuel is in the range of 10 pounds or less. Because of the limited data available, there is considerable uncertainty, perhaps of the order of 75% or more, in this value. The discrepancy of this relatively low quantity with the much higher EPA estimates noted above should be resolved definitively with additional data.

Sectors Affected

Diesel fuel is used primarily in heavy vehicles and emissions would be considered from mobile sources, both on- and off-road, throughout the State. Distillate oil is used for heating, electric power generation and steam production. Aircraft and airports use jet fuel. All public and private sectors are therefore affected by this source category.

Receiving Media

Since this is an uncontrolled combustion process as far as mercury is concerned, the primary receiving medium is air.

Chemical Species

The species emitted have not been confirmed through rigorous analysis or testing. Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species such as $HgCl_2$, and species bound to particulates are present. Fossil fuel combustion conditions create a milieu rich with methyl radicals[23] and from an energetic perspective, free radical reaction to produce RHgX is feasible.[24]

---

[20]. Gilkeson, John, 1999, Mercury in Petroleum Refining: Crude Oil and Refined Products, Final Report to Legislative Commission on Minnesota Resources, DRAFT, Minnesota Office of Environmental Assistance, August 20, 1999

[21]. Liang, L., M. Horvat, and P. Danilchik, 1996, A novel analytical method for determination of picogram levels of total mercury in gasoline and other petroleum based products, Science of the Total Environment, 187, 57-64.

[22]. The reported mercury concentration for kerosene, considered similar to jet fuel, is 0.04 ppb in the Liang, et al. reference noted above.

[23]. Glassman, I., 1996, Chapter 3, pp. 90-94, The Oxidation of Methane, in *Combustion, 3rd Edition*, Academic Press, San Diego.

[24]. DeNoble, James P., 1999, Critical Review: *Atmospheric Methylmercury: Sources, Sinks, and Inferences for its De Novo Generation*, DRAFT Masters Thesis, Rutgers University, October, 1999.

Reduction Options and Associated Costs and Impediments

Any effort that will reduce energy usage will have the collateral effect of lessening the impact of this category. No specific reduction options are proposed, however, because of the relatively low mercury concentration of this source.

Because of required product changes in the future, refinery processes will evolve. Evolution of oil refining processes may indicate ways to separate mercury from fuel products and further concentrate mercury in byproducts, which might be treated for mercury removal or disposed in ways that would not release mercury to air or water. The likelihood that mercury accumulates in the heavier liquid or solid products or byproducts (see discussion on oil refining) suggests that adaptations to segregate mercury may be relatively inexpensive. Refineries should take responsibility for determining where mercury contained in crude oil is concentrated in refinery products and byproducts. The use of the supplementary environmental project (SEP) enforcement mechanism to require process modifications and related efforts to prevent mercury pollution should be considered when and if any enforcement steps are necessary regarding oil refineries.

Research, Development, and Monitoring Options

Additional testing of distillate fuels is recommended using qualified state-of-the-art protocols and laboratories. A recent study has reported that mercury concentrations in crude oils range over 5 orders of magnitude, with a mean of 1.5 ppm.[25] This study did not report additional data on refined fuels. However, the variability of the mercury content of crude oils emphasizes the need for more data regarding mercury content of fuels and other refinery products and byproducts. Additional data will establish more certainty in the State's mercury inventory. Refinery processes should be investigated to determine ways to separate mercury from fuel products and further concentrate mercury in byproducts, as discussed above. EPA and the oil refining industry should be encouraged to implement further analyses and possible process improvements.

Outreach and Educational Options

Facilitate communications between the regulatory, scientific, and engineering communities, the petroleum industry, and fuel-using sectors.

Recommendations

- Promote energy conservation as a pollution prevention tool.
- Additional testing of distillate fuels using qualified procedures and laboratories.
- Investigate refinery processes to determine ways to separate mercury from products.

---

[25] Bloom, N.S., 2000, Analysis and stability of mercury speciation in petroleum hydrocarbons, Fresenius J. Anal. Chem., 366, 438-443.

Fuel Oil Combustion: Residual (Including #4 and #6 Fuel Oil)

Identification and Description of Source

Residual oil (number 6 fuel oil) is composed of the heaviest components of crude oil. It can be thought of as that portion of the crude oil that is left over when all other products are removed, hence the name "residual." It is believed that a majority of the residual oil consumed in the United States is imported. Mercury is thought to exist as a contaminant in residual oil. It is assumed that all mercury present in residual fuels will be released into the atmosphere during the combustion process. Most residual oil is burned to generate electricity or to provide power to relatively large industrial processes. It is also the prime fuel source for ocean-going ships.

Quantity and Estimated Uncertainty

Several stack tests have been performed in New Jersey on an electricity-generating unit burning residual oil.[26] The reported emission rate translates to a yearly emission of approximately 22 pounds if the facility was operating at full capacity. Based on an assumed thermal efficiency of this facility of 33%[27], it would consume the equivalent of about 4.1×10^6 megawatt hours of fuel (about 2.3 million barrels) if it operated at the tested rate for an entire year.[28] With an emission of 22 pounds of mercury per 2.3 million barrels (about 760 million pounds[29]) burned, the mercury concentration of the fuel can be estimated to be about 29 ppb. In 1997, New Jersey consumed about 9,348,000 barrels, or 58.8 trillion Btu, of residual oil.[30] This is equivalent to about 1.72×10^7 MWH.[31] Extrapolation of these stack test data to the entire state thus results in an estimated emission of 88 pounds of mercury from the combustion of residual oil. Because of the limited data available, there is considerable uncertainty in this value.

This value is higher than the estimated emission from the combustion of distillate fuels (see separate source write-up). Such a value is consistent with a finding of higher levels of mercury in residual oils, found to be in the range of 4 ppb in another recent study,[32] than in other refined fuels. It is also consistent with a report that suggests significant emissions of mercury from facilities burning residual oil in Florida.[33]

---

[26]. Klein, Michael, 1998, Memo from M. Klein, NJDEP to E. Choromanski, NJDEP. 12/23/98.

[27] 33% is typical of the thermal efficiency range of most large boilers.

[28]. The facility was operating at its capacity of 156 megawatts. Assuming 33% thermal efficiency and operation for 8760 hours, this facility would consume the equivalent 156 × 3 × 8760 megawatt hours of fuel, or 4.10×10^6 MWH.

[29]. The conversion factor used is one barrel of residual weighs 331 pounds.

[30]. USDOE, 1997, State Energy Data Report for New Jersey, U.S. Department of Energy, Energy Information Administration, downloaded from http:/www.eia.doe.gov/1pub/state.data/data, December, 1999.

[31]. The conversion factor used is 2.928×10^{-7} MWH per Btu.

[32]. Gilkeson, John, 1999, Mercury in Petroleum Refining: Crude Oil and Refined Products, Final Report to Legislative Commission on Minnesota Resources, DRAFT, Minnesota Office of Environmental Assistance, August 20, 1999.

[33]. Dvonch, J. T., J. R. Graney, G. Keeler, and R. Stevens, 1999, Use of elemental tracers to source apportion mercury in south Florida precipitation, *Environ. Sci. Technol.*, *33*, 4522-4527.

Sectors Affected

Residual oil is consumed in large boilers at utilities, commercial and industrial facilities. Facilities affected by this source category would include electric power generation, refining and large industrial facilities producing steam or electricity (for internal use).

Receiving Media

Since this is a combustion process with no air pollution control to catch any mercury, the primary receiving medium is air.

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species such as $HgCl_2$, and species bound to particles are present. It is also possible that some methyl mercury is emitted. Fossil fuel combustion conditions create a milieu rich with methyl radicals,[34] and, from an energetic perspective, free radical reaction to produce RHgX is feasible.[35] The species emitted have not been confirmed through rigorous analysis or testing.

Reduction Options and Associated Costs and Impediments

Any effort that will reduce energy usage will have the collateral effect of lessening the impact of this category. No specific reduction options are proposed, however, because of the relatively low mercury concentration of this source. Because of required product changes in the future, refinery processes will evolve. Evolution of oil refining processes may indicate ways to separate mercury from fuel products and further concentrate mercury in byproducts, which might be treated for mercury removal or disposed in ways that would not release mercury to air or water. The likelihood that mercury accumulates in the heavier liquid or solid products or byproducts (see discussion on oil refining) suggests that adaptations to segregate mercury may be relatively inexpensive. Refineries should take responsibility for determining where mercury contained in crude oil is concentrated in refinery products and byproducts. The use of the supplementary environmental project (SEP) enforcement mechanism to require process modifications and related efforts to prevent mercury pollution should be considered when and if any enforcement steps are necessary regarding oil refineries.

Research, Development, and Monitoring Options

Additional testing of residual fuels is recommended using qualified state-of-the-art protocols and laboratories. A recent study has reported that mercury concentrations in crude oils range over 5 orders of magnitude, with a mean of 1.5 ppm.[36] This study did not report additional data on refined fuels. However, the variability of this mercury content emphasizes the need for more

---

[34]. Glassman, I., 1996, Chapter 3, pp. 90-94, The Oxidation of Methane, in *Combustion, 3rd Edition*, Academic Press, San Diego.

[35]. DeNoble, James P., 1999, Critical Review: *Atmospheric Methylmercury: Sources, Sinks, and Inferences for its De Novo Generation*, DRAFT Masters Thesis, Rutgers University, October, 1999.

[36] Bloom, N.S., 2000, Analysis and stability of mercury speciation in petroleum hydrocarbons, Fresenius J. Anal. Chem., 366, 438-443.

data regarding mercury content of fuels and other refinery products and byproducts. Additional data will establish more certainty in the State's mercury inventory. Refinery processes should be investigated to determine ways to separate mercury from fuel products and further concentrate mercury in byproducts, as discussed above. EPA and the oil refining industry should be encouraged to implement further analyses and possible process improvements.

Outreach and Educational Options

Facilitate communications between the regulatory, scientific, and engineering communities, the petroleum industry, and fuel-using sectors.

Recommendations

- Promote energy conservation as a pollution prevention tool.
- Encourage a national program for residual fuel testing.
- Consider stack controls on any large identified sources to capture mercury.

Gasoline Combustion

Identification and Description of Source

Gasoline is a complex mixture of hydrocarbons having a boiling range between 100° and 400° F. Components are blended to promote high antiknock quality, ease of starting, quick warm-up, low tendency to vapor lock and low engine deposits. Components in New Jersey are also produced and selected to meet the reformulated fuel requirements of the Federal Clean Air Act Amendments of 1990.

Mercury is thought to exist as a trace contaminant in gasoline. It is assumed that all mercury present in gasoline will be released into the atmosphere during the combustion process.

Quantity and Estimated Uncertainty

No testing has been performed to quantify the total emissions from this source in the state of New Jersey. As with other analyses of mercury content of fuels, values reported in the literature based on studies that pre-date the use of ultra-clean laboratory techniques are considered suspect. Ultra-clean techniques, essential for accurate analyses of media containing low levels of mercury, did not become widely used until around 1990. Some analytical laboratories still do not use these techniques. Recent analyses of the mercury content of gasoline, have shown consistently low values, in the range of 1 ppb.[37,38]

The weighted average of 11 samples reported in the studies noted above and one other recently reported value of 20 ppb[39] is approximately 2.6 ppb. It is reported that 88,850,000 barrels of gasoline were consumed in New Jersey in 1997.[40] This is equivalent to about 2.3×10^{10} pounds.[41] Multiplying this quantity by the estimated concentration of 2.6 yields an estimated emission from this source of 60 pounds per year. Because of the limited data available, there is considerable uncertainty, perhaps of the order of 75% or more, in this value. If the actual values are closer to the upper end of the range, 20 ppb, the yearly emission could approach 460 pounds.

Sectors Affected

Gasoline is consumed in great quantities in New Jersey by mobile sources. All public and private sectors are therefore affected by this source category.

---

[37] Gilkeson, John, 1999, Mercury in Petroleum Refining: Crude Oil and Refined Products, Final Report to Legislative Commission on Minnesota Resources, DRAFT, Minnesota Office of Environmental Assistance, August 20, 1999.)

[38] Liang, L., M. Horvat, and P. Danilchik, 1996, A novel analytical method for determination of picogram levels of total mercury in gasoline and other petroleum based products, Science of the Total Environment, 187, 57-64.

[39] Florida DER, 1992, Florida Department of Environmental Regulation, 1992; Mercury Emissions to the Atmosphere in Florida, final report, Florida DER, 2600 Blair Stone Rd., Tallahassee, FL 32399.

[40] USDOE, 1997, State Energy Data Report for New Jersey, U.S. Department of Energy, Energy Information Administration, downloaded from http:/www.eia.doe.gov/1pub/state.data/data, December, 1999.

[41] The conversion factor of 258 pounds per barrel is used.

Receiving Media

Since this is an uncontrolled combustion process as far as mercury is concerned, the primary receiving medium is air. Because of the large volume of gasoline used in the state, the misuse or accidental release of gasoline could impact other media such as water and land, and the resulting cleanups could impact disposal sites. It is not known whether catalytic converters on motor vehicles could capture any mercury in the exhaust, and if so, whether any mercury so captured might remain at the time of vehicle disposal.

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species such as $HgCl_2$, and species bound to particles are present. It is also possible that some methyl mercury is emitted. Fossil fuel combustion conditions create a milieu rich with methyl radicals,[42] and, from an energetic perspective, free radical reaction to produce RHgX is feasible.[43] The species emitted have not been confirmed through rigorous analysis or testing.

Reduction Options and Associated Costs and Impediments

Any effort that will reduce energy usage will have the collateral effect of lessening the impact of this category. No specific reduction options are proposed, however, because of the relatively low mercury concentration of this source. The issues of vehicular fuel and transportation options are beyond the scope of the Task Force's efforts. Because of required product changes in the future, refinery processes will evolve. Evolution of oil refining processes may indicate ways to separate mercury from fuel products and further concentrate mercury in byproducts, which might be treated for mercury removal or disposed in ways that would not release mercury to air or water. The likelihood that mercury accumulates in the heavier liquid or solid products or byproducts (see discussion on oil refining) suggests that adaptations to segregate mercury may be relatively inexpensive. Refineries should take responsibility for determining where mercury contained in crude oil is concentrated in refinery products and byproducts. The use of the supplementary environmental project (SEP) enforcement mechanism to require process modifications and related efforts to prevent mercury pollution should be considered when and if any enforcement steps are necessary regarding oil refineries.

Add-on controls on engines are not proposed because of the low mercury concentrations and relatively low total amount of mercury from this source category. The costs associated are not defined.

---

[42] Glassman, I., 1996, Chapter 3, pp. 90-94, The Oxidation of Methane, in *Combustion, 3rd Edition*, Academic Press, San Diego.

[43] DeNoble, James P., 1999, Critical Review: *Atmospheric Methylmercury: Sources, Sinks, and Inferences for its De Novo Generation*, DRAFT Masters Thesis, Rutgers University, October, 1999.

Research, Development, and Monitoring Options

Additional testing of gasoline is recommended using qualified state-of-the-art protocols and laboratories. Mercury concentrations in gasoline may change due to ongoing efforts to reformulate this fuel, although the concentrations are likely to remain relatively low. A recent study has reported that mercury concentrations in crude oils range over 5 orders of magnitude, with a mean of 1.5 ppm.[44] This study did not report additional data on refined fuels. However, the variability of this mercury content of crude oils emphasizes the need for more data regarding mercury content of fuels and other refinery products and byproducts. Refinery processes should be investigated to determine ways to separate mercury from fuel products and further concentrate mercury in byproducts, as discussed above. EPA and the oil refining industry should be encouraged to implement further analyses and possible process improvements. The feasibility of developing exhaust gas controls that capture mercury should be investigated if future data indicate mercury emissions from gasoline combustion are significant.

Outreach and Educational Options

Communications between the regulatory, scientific, and engineering communities, the petroleum refining industry, and fuel-using sectors should be facilitated.

Recommendations

- Promote energy conservation as a pollution prevention tool.
- Encourage a national program for gasoline fuel testing.
- Encourage a statewide sustainable development program with a transportation and energy policy that reduces emissions of mercury and other pollutants.
- Consider development of exhaust pollution control devices that capture mercury.

---

[44] Bloom, N.S., 2000, Analysis and stability of mercury speciation in petroleum hydrocarbons, Fresenius J. Anal. Chem., 366, 438-443.

Natural Gas Combustion

Identification and Description of Source

Natural gas is a major fossil fuel source. It is used in utility and industrial boilers and combustion turbines, as well as in home and commercial home heating and water heaters.

Quantity and Estimated Uncertainty

At point of combustion, natural gas contains only trace quantities of mercury.[45] The 1997 EPA Mercury Report to Congress estimates that the national emission rate of mercury from utility boilers burning natural gas is 0.002 tons/year, or 4 pounds per year.[46] This estimate is based on 1994 -1995 data. Because the numbers are so low, EPA did not estimate the emission rates from industrial, commercial or residential users of natural gas. Pro-rating the national mercury emission rate due to natural gas to New Jersey results in a negligible quantity.

Sectors Affected

Utilities, industry, commercial and residential users of natural gas.

Receiving Medium

Since this is an uncontrolled combustion process as far as mercury is concerned, the receiving medium is air.

Chemical Species

The chemical species emitted from combustion of natural gas are unknown. Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particles are present.

Reduction Options and Associated Costs and Impediments
Research, Development, and Monitoring Options
Outreach and Educational Options

None. Emission rates are low.

---

[45]. Phannenstiel., L., McKinley, C., and J. Sorenson, 1976; Mercury in natural gas, presented at American Gas Association, Operational Section Transmission Conference, Las Vegas, NV, 76-T-12, p. T-202.

[46]. USEPA, 1997, Mercury Study Report to Congress, Volume II; An Inventory of Anthropogenic Mercury Emissions in the United States, EPA-452/R-97-004, December, 1997.

Petroleum Refining

Identification and Description of Source

Oil refineries do not produce mercury. Mercury is a contaminant in the crude oils used as a raw material source for the production of fuels. Due to the very large volumes of petroleum processed mercury releases could be substantial even if the concentrations of mercury in petroleum were very low.

Quantity and Estimated Uncertainty

As part of a comprehensive study of crude oils voluntarily undertaken by 5 of the 6 refineries in New Jersey, representative samples were taken on types of crude used as raw material, based on geographic location. These samples were analyzed by two laboratories that employ what are considered to be state-of-the-art procedures.[47] These same two laboratories were also used in another study of crude oil carried out in Minnesota.[48] The two laboratories used similar analysis procedures, but somewhat different extraction procedures to liberate mercury from crude oil and products. One laboratory, Cebam Analytical, Inc., used thermal decomposition to liberate the mercury; the other laboratory, Frontier Geosciences, Inc., employed a chemical extraction procedure using hot bromine monochloride. Both laboratories used cold vapor atomic fluorescence detection. As in the referenced Minnesota study, results from Cebam Analytical, Inc. were generally somewhat higher than from the other laboratory. The Minnesota researchers considered that Cebam Analytical, Inc. may have been more successful at liberating mercury from the samples, and concluded that use of the results of this lab represented both a worst case and a best estimate of the actual value. It is possible that the difference in values reported by the two laboratories represents a portion of mercury that exists in the crude oil and product samples in a chemically stable state, perhaps in the form of an organic complex.

In the study of the New Jersey refineries crude oil, the mercury concentration values reported by Cebam Analytical, Inc. have a mean 3.1 ppb, while the Frontier Geosciences, Inc. values have a mean of 1.5 ppb. In agreement with the conclusion of the Minnesota researchers, the results from Cebam Analytical, Inc. are considered to be both the worst case and best estimate of the total mercury content of the crude oil processed in New Jersey. When the individual analytical results from the various crudes used by each refinery are coupled with the quantities of these crudes processed, it is estimated that a total of approximately 270 pounds of mercury are contained in the crude that flows through New Jersey refineries each year. An inventory by refinery is included as a spreadsheet that is available from the Department.[49] The estimated uncertainty based on the data reported is considered to be modest, perhaps plus or minus 25%. However, it is likely that other crude oils have mercury concentrations that differ significantly from those reported in the New Jersey and Minnesota studies. A recent analysis of 76 samples of crude oils and condensates found that the mercury concentrations ranged over 5 orders of

---

[47]. Cebam Analytical, Inc., 3927 Aurora Ave. N., Seattle, WA 98103; and Frontier Geosciences, Inc., 414 Pontius North, Seattle, WA 98109.

[48]. Gilkeson, John, 1999, Mercury in Petroleum Refining: Crude Oil and Refined Products, Final Report to Legislative Commission on Minnesota Resources, DRAFT, Minnesota Office of Environmental Assistance, August 20, 1999.)

[49] Contact Michael Aucott, NJDEP, DSR&T, maucott@dep.state.nj.us, 609-292-7530.

magnitude, from 49.4 ppm , with a mean of 1.5 ppm.[50] Other reports suggest that crudes from Southeast Asia[51] and California[52] may have a higher mercury content than the crudes refined in New Jersey, which are mainly from Western and Northern Africa, the North Sea, South America, and the Arabian Peninsula .

Sectors Affected

Refineries themselves are the only sector affected. Sources from combustion of the refined fuels produced by refineries are discussed in sections devoted to these fuels.

Receiving Media

The disposition of the mercury in the crude could be air, land, or water. It could find its way to disposal sites for refinery byproducts or become part of the products of the refinery such as diesel fuel or gasoline. Based on limited data on fuel gases used during the processing of these low mercury crudes, air emissions are below the deminimus level of 2 lbs./yr. required for inclusion in air permits.[53] Available data on API (American Petroleum Institute) separator thickener tank solids (primary wastewater treatment sludge) disposed off site by one refinery indicated that this waste shipped off-site in 1998 for incineration by a cement kiln contained an estimated 22 pounds of mercury.[54] RCRA type K waste sludge material from refinery operations, believed to be [presumably] oil/water separator sludge from a Pennsylvania refinery that was processed by a processor of sludge, was reported to be as high as 60 ppm.[55] Although data are still too limited for a firm conclusion, the relatively high mercury levels reported in these refinery waste sludge materials, and the mercury concentrations estimated to be present in residual oil (see separate source write-up) suggest that much of the mercury present in crude oil may concentrate in the heavier, less-volatile product and waste streams.

Chemical Species

All testing was for total mercury; different mercury molecular species were not identified. Because the concentrations are near the detection level, speciation of the mercury in crude would be difficult with current analytic techniques. Also, the species existing in the crude might be different from the species in the medium through which the mercury leaves the refinery.

---

[50]. Bloom, N.S., 2000, Analysis and stability of mercury speciation in petroleum hydrocarbons, Fresenius J. Anal. Chem. 366, 438-443.

[51]. Wilhelm, S. M., 1996, Technical Overview of Mercury Waste Issues in SE Asia and Options for Disposal, Society of Petroleum Engineers, Inc., PO Box 833836, Richardson, TX 75083-3836, downloaded from http:/www.hgtech.com/waste.htm, 9/17/98.

[52]. Hansell, D. and G. England, 1997, Air Toxic Emission Factors for Combustion Sources Using Petroleum-based Fuels, Vol. 1., prepared for S. Folwarkow, Western States Petroleum Association, 2300 Clayton Rd., Suite 1440, Concord, CA 94520 and Karen Ritter, American Petroleum Institute, 2020 L Street, NW, Washington, DC 20005, October 17, 1997. This report provides a mercury emissions factor for crude/pipeline oil of 1.0×10^{-5} lb./MMBtu; calculations performed by M. Aucott, NJDEP, indicate that this factor corresponds to a total mercury content in the crude/pipeline oil of approximately 190 ppb.

[53]. Letter from Stephen Martini, Coastal Eagle Point Oil Company, to Richard Langbein, NJDEP, May 7, 1999.

[54]. Letter from S. Martini, Coastal, to R. Langbein, NJDEP, May 7, 1999

[55]. Joel Leon, NJDEP, personal communication, December 10, 1999.

Reduction Options and Associated Costs and Impediments

None are identified because of the lack of understanding of disposition of the mercury in the crude once it is processed. Also, refinery processes associated with the production of liquid fuels are in a state of flux because of clean air considerations. There are no data on the impact of these changes on the distribution of mercury within the process and products. Because of required product changes in the future, refinery processes will evolve. Evolution of oil refining processes may indicate ways to separate mercury from fuel products and further concentrate mercury in byproducts, which might be treated for mercury removal or disposed in ways that would not release mercury to air or water. The likelihood that mercury accumulates in the heavier liquid or solid products or byproducts (see discussion on distillate oil combustion) suggests that adaptations to segregate mercury may be relatively inexpensive.

It is reported that simple, low-investment feedstock treatment procedures have been developed that eliminate Hg (and also arsenic) impurities with high efficiencies.[56] Refineries should take responsibility for determining where mercury contained in crude oil is concentrated in refinery products and byproducts. The use of the supplementary environmental project (SEP) enforcement mechanism, which allows actions with environmental benefits to be carried out in lieu of fines, to require process modifications and related efforts to prevent mercury pollution should be considered when and if any enforcement steps are necessary regarding oil refineries.

Any efforts that will reduce energy usage will have the collateral effect of lessening the impact of this category by reducing the amount of petroleum processed each year.

Research, Development, and Monitoring Options

The inventory of analytic data on crude oil, refinery waste streams, and refinery products should be updated by the year 2005. Much of the data in the literature regarding mercury in crudes based on studies that pre-date the use of ultra-clean laboratory techniques are considered suspect. Ultra-clean techniques, essential for accurate analyses of media containing low levels of mercury, did not become widely used until around 1990. Some analytical laboratories still do not use these techniques. All analytical work done in connection with the sampling of crude oil from New Jersey refineries as discussed herein was performed by laboratories using what are believed to be state-of-the-art methods, achieving very low detection limits. All future analytical work should be performed using latest methods and ultra-clean techniques.

A quantified determination of the fate of mercury in crude oil is needed, as is better understanding of how mercury concentrations in fuel products can be minimized.

Outreach and Educational Options

There should be outreach to the refining industry to encourage a better quantification of the fate of mercury in crude oil and to determine how mercury concentrations can be minimized in fuel products.

---

[56] Sarrazin, P., C. Cameron, Y. Barthel, and M. Morrison, 1993, Processes prevent detrimental effects from As and Hg in feedstocks, *Oil and Gas Journal*, Jan 25, 1993.

Recommendations

- Investigate processes to determine ways to separate mercury from fuel products prior to distribution.
- By 2005, update the inventory of mercury in crude oil and its fate.
- Encourage reduced energy use by refineries and other energy users.

Wood Combustion

Identification and Description of Source

Wood and wood wastes may be burned for residential heating or as a commercial energy source. Mercury is expected to be present in wood in trace quantities from root uptake from soil, and deposition of airborne mercury to leaves, buds and bark. Waste wood may contain mercury (or other metals) in paints that had been applied to surfaces.

Wood stoves are enclosed wood heaters used as residential space heaters. There are five different types of wood stoves: (1) the conventional wood stove; (2) the non-catalytic wood stove (emission reducing technology); (3) catalytic wood stove; (4) the pellet stove; and (5) the masonry heater.

Fireplaces are used generally for aesthetic effects and secondarily as supplemental heating. Although wood is usually the fuel for fireplaces, coal and compressed wood "logs" may also be burned.

Quantity and Estimated Uncertainty

Wood stoves and fireplaces operate at temperatures above the boiling point of elemental mercury. As a result, any mercury in the wood can be expected to be emitted with the combustion gases. Although some wood stoves use emission controls to reduce volatile organic compound and carbon monoxide emissions, the measures are not expected to affect mercury emissions.

USEPA has recommended that an emission factor of 5.2×10^{-6} lb. mercury/ton of wood be utilized when estimating mercury emissions from commercial wood-fired boilers.[57] Residential stoves and fireplaces could be expected to burn wood that is no higher in mercury. Therefore, use of the same emission factor is reasonable. In 1997, the US Department of Energy estimated that wood consumption for combustion in New Jersey was 604,000 cords for residential housing, while commercial use was estimated at 59,000 cords. Industrial use as cords was not available; however, consumption estimated at 17.9 trillion Btu was used for calculations.[58] The densities of wood vary depending on wood type and the moisture content of the wood. Generalized density

---

[57] USEPA, 1997, *Mercury Study Report to Congress, Volume II; An Inventory of Anthropogenic Mercury Emissions in the United States*, EPA-452/R-97-004, December, 1997.

[58] USDOE, 1997, *State Energy Data Report for New Jersey*, U.S. Department of Energy, Energy Information Administration, downloaded from http:/www.eia.doe.gov/1pub/state.data/data, December, 1999.

conversion factors for hardwoods and softwoods expected to be burned in New Jersey result in an estimated density of 36 pounds per cubic foot of wood.[59]

Using these factors, and the fact that one cord is equal to about 79 ft^3, emissions from residential,[60] commercial,[61] and industrial combustion[62] were calculated as 4.5 lbs./yr., 0.4 lbs./yr. and 5.4 lbs./yr., respectively. The estimated yearly total is 10 pounds.

Sectors Affected

Those who burn wood in any sector could be affected by measures to control this source.

Receiving Media

Any mercury found in wood will be volatilized and be emitted with the combustion gases through the exhaust stack into ambient air.

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particles are present.

---

[59] Factors to Convert Wood Volume (ft^3) to Weight (lbs.)

	Forest type	Softwoods	Hardwoods
Northeast and Mid-Atlantic Region	Pines	23.6	33.8
	Spruce-Fir	23.0	32.8
	Oak-Hickory	23.3	39.7
	Maple-Beech-Birch	24.0	37.4
	Bottomland Hardwoods	28.7	36.2

[60] Wood Weight = 604,000 cords burned x 79 ft^3 x 36.0 lbs/ft^3 = 1,717,776,000 lbs., or 858,888 tons wood burned. 5.2 x 10^{-6} lb. mercury/ton wood x 858,888 tons wood burned = 4.5 lb. estimated mercury emissions from residential wood combustion

[61] Wood Weight = 59,000 cords burned x 79 ft^3 x 36.0 lbs/ft^3 = 167,796,000 lbs., or 83,898 tons wood burned. 5.2 x 10^{-6} lb. mercury/ton wood x 83,898 tons wood burned = 0.4 lb. estimated mercury emissions from commercial wood combustion.

[62] Cord usage information was not available for the industrial category; however, estimated energy consumption (17.9 trillion Btu) was used with appropriate conversion factors. 5.2 x 10^{-6} lb. mercury/ton wood x 17.9 trillion Btu/yr. x lb./8600 Btu x 1 ton/2000lbs. =5.4 lbs. mercury/year.

Reduction, Research, Development and Monitoring; Outreach and Educational Options; and Associated Costs and Impediments

Given the low total quantity, consideration of reduction options is not warranted.

Cultural Uses

Identification and Description of Source

A potentially widespread but little understood source of mercury involves cultural uses in Latino and Afro-Caribbean communities.[63,64] The Task Force invited a presentation by Dr. Arnold Wendroff of the Mercury Poisoning Project (Brooklyn, NY), who reported on studies underway in New York and recommended similar investigation in New Jersey. While the total amounts of mercury used are small on a state-wide or industrial scale, its use in small enclosed spaces creates the potential for very high direct exposures to individuals. The Task Force endorsed the need to obtain more information and develop at least informational, if not regulatory, approaches to reducing this avenue of exposure and possible outdoor, as well as indoor contamination.

Availability and Extent of Use

In the United States, certain Afro-Caribbean and Latin American traditions incorporate the use of elemental mercury in folk medicine and cultural practice. Mercury is sold in most botanicas, stores specializing in herbal remedies and items used in various cultural practices including Santeria (Lukumi), Voodoo, and Espiritismo.[65,66]

Several surveys have attempted to characterize mercury use in Latino and Afro-Caribbean communities. In a survey of New York botanicas, 93% reported selling mercury (about one to four capsules per day). A survey of 115 botanicas in 13 cities in the U.S. and Puerto Rico found that 99 sold mercury[67,68]. A survey of 203 Caribbean and Latin American adults in the New York City area found that 44% of Caribbean and 27% of Latin American respondents reported using mercury.[69] However, an ATSDR study of Santeria practitioners in Hartford, Connecticut's Hispanic community found only 14% reported using mercury in the home. *Johnson*[70] looked more generally at folk medicine and cultural practices, finding use outside of Santeria. Similarly, *Zayas and Ozuah*[71] found that santeros (Santeria priests) were mentioned by store proprietors as the source of mercury recommendations less than 10% of the time.

---

[63]. Pinn, A. Varieties of African American Religious Experience. Minneapolis: Fortress Press, 1998.

[64]. Many cultures have traditions involving potentially harmful chemical exposures. Consider, for example, the German *Sylvester* (New Year's Eve) tradition of *Bleigiessen*, which typically involves melting lead on a stove top, then pouring it into a basin of cold water, for the purpose of telling fortunes for the coming year.

[65]. Wendroff, A. (1990). Domestic Mercury Pollution, *Nature*, **347**: 623.

[66]. Zayas, L.H. and Ozuah, P. O. (1996). Mercury Use in Espiritismo: A Survey of Botanicas. *American Journal of Public Health*, **86**(1): 111-112.

[67]. Wendroff, A. (1990). Domestic Mercury Pollution, *Nature*, **347**: 623.

[68]. Johnson, C. (1999). "Elemental Mercury Use in Religious and Ethnic Practices in Latin American and Caribbean Communities in New York City," *Population and Environment*, **20** (5): 443-453.

[69]. Johnson, C. (1999)

[70]. Johnson, C. (1999)

[71]. Zayas, L.H. and Ozuah, P. O. (1996)

Uses

Mercury is typically sold in capsules that contain, on average, about 8 or 9 grams (0.3 oz.) of mercury[72]. The most common method of use reported by botanica personnel was carrying mercury on the person in a sealed pouch (48.8%) or in a pocket (31.7%) as an amulet, while sprinkling mercury in the home was mentioned by 29%. Proprietors reported that family members, friends, spiritualists, and card readers recommend mercury to store patrons to bring luck in love, money or health and to ward off evil.[73] A survey of Latin American and Caribbean New York residents[74] found that burning mercury in a candle, mixing it with perfume, or sprinkling it in the car were also frequently reported uses. Of 28 New York botanicas visited in another survey, 13 prescribed sprinkling mercury on the floor.[75] Mercury poisoning has also been documented in Mexican-American infants fed mercury as a folk remedy for gastroenteritis.[76]

Impacts

As a result of these practices, living spaces may become contaminated with mercury. Removal of mercury from floorboards and carpets is difficult if not completely impractical.[77] These mercury practices are a direct source of contamination not only to the users and their families, but also to people living in adjacent apartments, and to any future residents of the premises. The extent of use is unknown, and the magnitude uncertain, but there is potential for high exposures in this sub-population.

Although this source of mercury has only recently come to the attention of public health officials, the potential liability to landlords is significant. In addition, much of the mercury used in folk medicine and cultural practice may be disposed of improperly. *Johnson*[78] found that 64% of mercury users in his study reported throwing mercury in the garbage, while 27% flushed it down the toilet and 9% threw it outdoors.

Quantity and Estimated Uncertainty

---

[72]. Wendroff, A. (1990). Domestic Mercury Pollution, *Nature*, **347**: 623.

[73]. Zayas, L.H. and Ozuah, P. O. (1996)

[74]. Johnson, C. (1999)

[75]. (Wendroff, 1990).

[76]. Geffner, M.E. and Sandler, A. (1980). "A Folk Medicine Remedy for Gastroenteritis." *Clinical Pediatrics*, **19**(6): 435-436.

[77]. Smart, E. R. (1986). Mercury Vapour Levels in a Domestic Environment Following Breakage of a Clinical Thermometer. *Science of the Total Environment*, 57: 99-103.

[78]. Johnson, C. (1999)

An estimate of exposure was based on available data from New York City.[79,80] In New York 100-300 capsules were reported sold each day in 35 botanicas.[81] Based on 1990 census estimates of 720,000 Hispanics in New Jersey as opposed to 1.7 million in New York City (five boroughs), one can estimate that 13,000-38,000 capsules are sold in New Jersey each year, for a total of 100-350 kg (200-800 lbs.) of mercury. Of this, 10-30 percent (10-100 kg/year, or 20-200 lbs.) is intentionally sprinkled on the floor indoors.[82,83] Additional exposures through accidental spillage or breakage of capsules, or through other practices (such as burning mercury in an oil lamp) may also occur, but such events are reported less frequently.[84,85] A lower-bound estimate of exposure can be derived by assuming households use an average of 2 capsules per year (10 kg total, 8-9 g per capsule), resulting in 600 households (1200 individuals) exposed per year in New Jersey. An upper bound estimate of exposure can be derived from *Johnson*[86] who found 27 percent of Latin Americans interviewed reported using mercury. If 30 percent of these users[87] sprinkle it on the floor, approximately 60,000 New Jersey residents would be exposed. These estimates vary widely, and more data specific to New Jersey are required to refine these estimates and properly characterize the extent and severity of the problem.

Sectors Affected

The residential sector is potentially affected.

Receiving Media

Through the practices described herein, mercury could ultimately be released to air, wastewater, or the municipal solid waste stream.

Chemical Species

It is believed that only elemental mercury is involved.

Research, Development, and Monitoring Options/Recommendations

More studies are needed to characterize exposure among cultural users of mercury, to understand the perceptions of risk in Latino and Caribbean communities, and to develop effective interventions, including risk-communication materials that address the beliefs and behaviors specific to those communities.

---

[79]. Johnson, C. (1999)
[80]. Zayas, L.H. and Ozuah, P. O. (1996)
[81]. Zayas, L.H. and Ozuah, P. O. (1996)
[82]. Zayas, L.H. and Ozuah, P. O. (1996)
[83]. Johnson, C. (1999)
[84]. Johnson, C. (1999)
[85]. Zayas, L.H. and Ozuah, P. O. (1996)
[86]. Johnson, C. (1999)
[87]. (Zayas and Ozuah, 1996)

NJDEP and/or NJDHSS should participate or review the following research projects and utilize the information to enhance other activities.

1. Clinical studies to identify mercury levels in people, either studying the mercury-using community vs. control groups or Latino and Caribbean populations vs. other groups. Where possible, connections should be made to the sources of exposure.
2. Ethnographic research to identify the needs, beliefs, and exposure patterns in specific subpopulations, and to understand the frequency and extent of different uses, sales rates, mercury supply chains, etc. Participant observation should be a particularly effective research tool for this work.
3. Risk perception and risk communication research that evaluates the effectiveness of communication materials and outreach strategies, and provides input for improved designs for both.
4. Fate and transport studies of mercury in indoor air to better relate sources to exposure levels, and to develop reliable models to predict indoor concentrations. Air measurements in residences and botanicas to validate these models and measure typical exposure levels stemming from cultural and religious uses.
5. Epidemiology and toxicology studies aimed at understanding low-level health effects and the importance of dermal exposure.

The EPA Office of Research and Development (ORD), ATSDR, CDC and the National Association of City/County Health Officials (NACCHO) are just some of the agencies expected to support and monitor many of the research projects identified above.

Based on the results of EPA's recent study, develop/adopt a protocol for environmental monitoring that uses new screening instruments that have greater accuracy.

Outreach and Educational Options/Recommendations

Because botanicas represent a critical link to health care services in Latino and Afro-Caribbean communities, it is important to recognize the role of botanicas in providing culturally congruent health interventions in their communities.[88,89,90] Any public health interventions to reduce mercury exposure must recognize the important role botanicas play as the first place many turn for general health care services in Latino and Caribbean communities, and work with spiritualists, santeros, and botanica proprietors in addressing the problem.

Community Outreach and Education

NJDEP and NJDHSS will conduct a coordinated effort among state and local health departments and local community organizations to help inform mercury suppliers and the public about mercury's risks. Activities to be performed include:

---

[88]. (Zayas and Ozuah, 1996)

[89]. Pasquali, E. A. (1986). Santeria: a religion that is a health care system for Long Island Cuban-Americans. *Journal of New York State Nurses Association*, **17**(1): 12-15.

[90]. Pasquali, E. A. (1994). Santeria. *Journal of Holistic Nursing*, **12**(4): 380-390

Distribute educational materials on mercury for use by state and local environmental and health departments and community groups. Materials include:

1. Draft brochure with general focus
2. Brochure developed by EPA that is specific to religious uses and is available in multiple languages
3. Provide sample labels for mercury (to be developed with input from EPA, ATSDR, CPSC, and community groups) and distributed with support from ATSDR's network to botanicas.

B. Contact publishers and authors of religious/spirituality books that contain mercury spells, to request inclusion of a specific note about the risks of using mercury and how to reduce risk in practice or a consideration of alternative spells that use non-toxic substances.

C. Develop and implement, along with assistance from ATSDR and EPA, an effective outreach strategy for local health departments, focusing on community-based organizations, schools, and businesses. Such a strategy should include:

2. Distribution of materials mentioned above
3. Presentations to local civic organizations
4. Answering health related questions and concerns at community coordination centers and public availability sessions
5. Providing training and materials for persons responding to community questions and concerns
6. Working with spiritual leaders to identify and encourage the use of non-toxic alternatives to mercury
7. Outreach to other community groups or organizations affected by mercury
8. Evaluation of the effectiveness of the outreach program

D. Send out the letter, once finalized and approved, in Attachment I to all local and state government contacts in area that are considered to be of concern.

Health-care Provider Outreach and Education

1. NJDEP and NJDHSS, along with ATSDR, will work with district and local health departments, provide education to health professionals, including alternative or nontraditional health care providers. Building these relationships could result in enlisting some hospitals or clinics in clinical data gathering efforts. Health professional education includes:
2. Distribution of physicians resource guides (such as those developed by Connecticut DHS and New York City DOH)
3. Presentation of grand rounds at local hospitals
4. Direct consultation with health care providers
5. Distribution of educational materials such as the *Case Studies in Environmental Medicine* to all health care providers in impacted areas
6. Provide training for health professionals on the possible psychological effects of mercury exposure

Legislation Efforts

1. New Jersey should develop and implement appropriate legislation and regulations that limit the sale of elemental mercury, except for medical and other approved uses, reflecting the NEWMOA model legislation.[91]

---

[91] See http://www.newmoa.org/prevention/mercury/programs

Fluorescent Lamps

Identification and Description of Source

Fluorescent and high-intensity discharge (HID) lamps (except for low-pressure sodium lamps) contain mercury. Approximately 95% of the mercury–containing lamps used in the United States are linear fluorescent light tubes.[92] The remainder are either compact fluorescents or specialty lamps produced for commercial or municipal use, such as street lighting. These include mercury vapor lamps, metal halide lamps, high-pressure sodium lamps, and neon lamps. The following discussion focuses on linear fluorescent tubes.

The amount of mercury in linear tubes has declined significantly over the past 15 years. According to a January 2001 industry report, the average mercury content of 4-ft. lamps has been reduced from 48.2 mg in 1985 to 41.6 mg in 1990, to 22.8 mg in 1994, to 11.6 mg in 1999.[93] The majority of fluorescent lamps in service in the United States are T12 lamps (1.5 in. diameter), containing an average of 22 milligrams according to the latest data.[94] T8 lamps (1 in. diameter) are also available. Designed to be more energy-efficient due to reduced tube volume, T8s also contain less mercury - an average of 14 mg. (Increased energy efficiency can be expected to result in reduced mercury emissions from power generation facilities.)

Since 1995 average amounts of mercury in all tubes has declined due to the introduction of "low-mercury" bulbs (both T12 and T8) by all three major manufacturers. Low-mercury lamps contain less than 10 milligrams of mercury. Both Osram Sylvania and GE Lighting quote a range of mercury content for their low-mercury lamps. Philips maintains that proprietary technology allows them to control the amount of mercury better than their competitors.[95] No fluorescent bulbs currently on the market are mercury-free.

Based on most lamps' rated life of 20,000 hours, tubes being discarded today may be estimated to be about 5 years old, and hence may contain, on the average, about 20 mg of mercury. Independent studies of lifetimes of available lamps have not been found. Variables affecting lamp life may include use patterns and types of ballasts used.

While EPA has published data on the total mercury content of the various types of 4-ft. fluorescent lamps, the agency states that the speciation is very uncertain.[96] The form of mercury in fluorescent lamps depends on a number of factors such as the age of the lamp, the type of lamp, and the method of lamp operation. At room temperature, less than 0.02 mg is in the elemental vapor state, about 0.1 mg is in the form of solid chemical compounds such as mercury oxide (HgO), and the balance is present as elemental liquid mercury distributed on the surface of

---

[92] Northeast States for Coordinated Air Use Management (NESCAUM), et al., 1998, *Northeast States/Eastern Canadian Provinces Mercury Study, A Framework for Action*, February, 1998, p. VII-5.

[93] National Electrical Manufacturers Association (NEMA), *Fluorescent Lamps and the Environment*, http://www.nema.org/lamprecycle/nemafluorfinal.pdf.

[94] Walitsky, Paul, Philips Electronics, Inc., personal communication, February, 2001.

[95] Walitsky, Paul, Philips Electronics, Inc., personal communication, February 27, 2001

[96] U.S. Environmental Protection Agency, 1998. *Mercury Emissions from the Disposal of Fluorescent Lamps, Revised Model, Final Report.* Office of Solid Waste. Washington, D.C. March 31, 1998.

the phosphor and other internal parts. At lamp operating temperatures (approximately 40 degrees C) the amount of elemental mercury vapor increases, but does not exceed 0.05 mg.

Elemental mercury dispersed throughout the lamp exists as very small particles or beads that are typically too small to be seen with the naked eye.[97,98] Elemental mercury is introduced into the lamp during manufacture as a single charge, but becomes dispersed as the lamp operates because a certain amount of the mercury vaporizes each time the lamp heats up during operation, and then condenses into tiny droplets as the lamp cools.[99] As the lamp ages, an increasing amount of elemental liquid mercury is converted to solid mercury compounds (principally HgO). The quantity converted to HgO is between 1 and 4 mg at the end of the lamp's rated life.[100] A significant amount of the mercury originally present as elemental is also expected to become bound to the glass as the lamp ages.[101]

When mercury-containing lamps are broken, elemental mercury vapor, liquid mercury and phosphor powder containing adsorbed mercury can be released. In addition, small pieces of glass and other lamp components, such as aluminum end caps, will be contaminated with mercury and can release it to the environment if not managed properly.

Many of the fluorescent lamps in use in the United States today must be classified as hazardous waste when they are discarded because they fail the Toxicity Characteristic Leaching Procedure (TCLP) test used to categorize hazardous waste under the Resource Conservation and Recovery Act (RCRA). On the surface, it would seem that this requirement could direct mercury-containing lamps to an appropriate management facility and thus mitigate mercury releases from this source. However, the RCRA program has proven to be ineffective as a management system for fluorescent lamps for two primary reasons: 1) not all fluorescent lamp disposers are aware that their spent lamps may be hazardous waste and 2) millions of spent lamps are exempt from the RCRA regulations because they are disposed by households or conditionally exempt small quantity generators (CESQGs). CESQGs are businesses or facilities that are exempt from hazardous waste disposal requirements because they dispose of less than 100 kg of hazardous waste per month (300-350 4-ft. T12s or 400-450 4-ft. T8s). Both of these realities lead inevitably to the annual disposal of millions of spent fluorescent lamps through municipal and private waste collection systems.

EPA recognized that certain types of wastes, including certain used lamps, could be better managed under its Universal Waste Rule (UWR), first issued in 1995.[102] The rule was promulgated to facilitate proper collection, recycling and treatment of nickel-cadmium and other batteries, certain pesticides and mercury-containing thermostats that were classified as hazardous waste under the RCRA regulations. The UWR was also intended to establish a prototype system that could be expanded to include other wastes in the future. The 1995 rule did not include spent

---

[97] Erdheim, Richard, National Electric Manufacturers' Association, personal communication, August 25, 2000.

[98] Bleasby, Peter, Osram Slyvania Corp., personal communication, August 25, 2000.

[99] Walitsky, Paul, Philips Electronics, Inc., personal communication, August 25, 2000.

[100] National Electric Manufacturers' Association (NEMA), 2000, NEMA, Rosslyn, VA.

[101] Walitsky, Paul, Philips Electronics, Inc., personal communication, August 25, 2000.

[102] USEPA, 60 FR 25542, May 11, 1995

lamps that were classified as hazardous waste. But after further consideration and study of the mercury issue, EPA issued a final rule on July 6, 1999 that added hazardous waste lamps to the federal list of universal wastes.[103] The addition of spent fluorescent lamps to the universal waste list was designed to encourage recycling of spent lamps and remove them from municipal landfills and incinerators, by eliminating some of the regulatory requirements (such as manifesting and transportation restrictions) that are assumed to deter businesses from proper disposal. Spent fluorescent lamps were added to the federal rule on January 6, 2000.

In December 1996, New Jersey adopted the federal UWR, managing certain batteries, thermostats and spent pesticides as universal wastes in the state.[104] These wastes were then designated as Class D recyclable materials and are managed under New Jersey's Recycling Rules (N.J.A.C. 7:26A). In that same year, the New Jersey Department of Environmental Protection (NJDEP) began a feasibility study to determine whether spent mercury-containing lamps (classified as hazardous waste) could be safely handled as universal wastes, and should be added to the New Jersey UWR.[105] The NJDEP identified five waste collection facilities to participate in the study, and the department monitored collection and handling activities over the period of the test. All test facilities collected discarded lamps, including the standard 4-foot fluorescent lamps, for recycling. The results of the NJDEP's evaluation were favorable. Amendments to the New Jersey UWR which will include mercury-containing lamps as universal wastes under the same terms as the federal rule are currently in the administrative review cycle within the NJDEP, with adoption expected in mid-2001.

One potential problem with exempting generators from RCRA requirements is that, although technically liable for future cleanup costs, etc., in practice these generators are likely to continue to dispose of tubes in the trash. Some disagreement exists as to how many generators—and how many lamps—are unregulated under the UWR. U.S. EPA estimates about 20 percent of generators are excluded under UWR; the California Environmental Protection Agency believes the number is much higher, at 40–50 percent.[106]

The NJDEP collected data from the five lamp-recycling or collection facilities that participated in the original feasibility study. This data, summarized below, represents the total amount of mercury, by linear feet of tubes, collected for the periods indicated.

Table 1: Linear feet of mercury-containing fluorescent tubes collected

Facility	Program Dates	Amount Recycled (linear feet)
Morris County Municipal Utilities Authority	03/97 – 02/99	302,366
Union County Municipal Utilities Authority	04/96 – 02/99	354,018
Burlington County Office of Solid Waste Management	05/96 – 02/99	112,508

---

[103] USEPA, 64 FR 36467, July 6, 1999

[104] 28 N.J.R. 5360

[105] New Jersey Department of Environmental Protection, Division of Solid and Hazardous Waste, Trenton, NJ

[106] Sustainable Conservation, *Reducing Mercury Releases From Fluorescent Lamps: Analysis of Voluntary Approaches*, prepared for the Bay Area Dischargers Association, September 2000, p. 21.

Public Service Electric & Gas Company	07/99 – 12/99	200,019
Global Recycling Technologies	07/99 – 01/00	1,319,288

Because the feasibility study results were favorable and because the EPA rule categorizing fluorescent tubes as universal waste is in effect, the NJDEP is allowing facilities to manage spent fluorescent lamps as universal waste while the regulations are in the administrative review phase. The NJDEP is requiring such activities to be carried out in strict adherence to the universal waste rules. Lamp crushing and other "processing" activities, viewed as treatment, are prohibited at any New Jersey facility that does not have a hazardous waste treatment permit that covers the processing activities. Broken fluorescent lamps must be handled as hazardous waste. Bulbs broken in transit or handling can be handled as a universal waste, provided the breakage amounts are incidental.

Fluorescent lamp recycling generally involves the crushing of intact lamps in a closed system, followed by heating, or "cooking," in a retort/distillation unit to drive off residual mercury from the crushed components. Temperatures used in a typical retort/distillation unit are at or near 1,000° F.[107] Mercury released as vapor is collected for sale or reuse. After crushing, the phosphor powder, glass and metal produced is further treated one of two ways, depending on the recycling facility. One treatment method passes the crushed materials through a separator before treatment in a retort/distillation unit. The metal and glass components are collected without further treatment, and only the phosphor powder is fed to the retort/distillation unit for cooking. This process typically reclaims only about half of the mercury in the lamp, as much of it has become bound to the glass as the lamp ages. The second treatment process feeds all crushed lamp components to the retort/distillation unit, and separates the glass, metal and phosphor components after treatment. This process captures more than 99 percent of the mercury.[108] The materials produced by recycling facilities are not considered hazardous waste after treatment and are reused, if possible. The glass in the lamp can be recycled with other soda-lime glass, the mercury is recycled to new lamps or other manufacturing processes, and the aluminum is recycled with other aluminum like soda cans. The phosphor powder currently is not recycled because no significant use has been identified. It is important to distinguish between the two recycling methods because glass and metal lamp parts that have undergone mercury removal via the first method may contain residual mercury. This residual mercury may be released during manufacturing (by heating or washing) if the components are used to produce new products.

The cost of recycling fluorescent lamps is decreasing, and the industry foresees that it will continue to lower with increased demand for recycling and as technology for retorting larger batches of crushed lamps comes on line. In 1998, Osram Sylvania estimated that it costs approximately $4,000 per pound to recover mercury through recycling.[109] In 2001, Bethlehem Apparatus stated that their per-lamp cost of mercury reclamation had come down to $0.05 per 4-ft. tube for high-volume generators, from $0.50 several years ago.[110] However, Osram Sylvania

---

[107] Lawrence, Bruce, President, Bethlehem Apparatus Company, Inc., personal communication, July 13, 2000.

[108] John Boyle, Bethlehem Apparatus Company, personal communication, March 13, 2001.

[109] Osram Sylvania, 1998, *Osram Sylvania – Position on Lamp Disposal Issues* (Press Release), January 26, 1998, Osram Sylvania, Danvers, Massachusetts.

[110] Ibid.

estimated in 1998 that the value of recycled mercury suitable for use in fluorescent lamp manufacturing was between two and three dollars per pound. As lamp manufacturers continue to reduce the mercury content of the fluorescent lamps they produce, the recovery cost per unit (or per pound of mercury) may increase further. Thus, the economics of recycling will not be an incentive to recycle fluorescent lamps. However, the avoided cost of either disposing of mercury-containing products as hazardous waste or removing mercury from trash incinerator emissions - as well as the public's insistence on removing mercury from the environment - may be the operative factors for this industry

Quantity and Estimated Uncertainty

As stated above, the amount of mercury in a 4-ft. linear fluorescent lamp has declined from an average of nearly 50 mg in lamps manufactured in 1986 to an average 11.6 mg for lamps manufactured today[111], with some low-mercury lamps containing less than 4 mg.[112] As noted above, it can be estimated that fluorescent tubes currently in the disposal stream contain an average of approximately 20 mg of mercury. Approximately 620 to 780 million lamps were discarded in the U.S. in 1999.[113,114] The mid-point estimate is 700 million lamps discarded. It can be assumed, based on population, that approximately 21 million lamps were discarded in New Jersey in 1999. If each lamp contains an average of 20 mg of mercury, the total mercury in lamps discarded in New Jersey is currently in the range of 925 pounds annually.

The fate of this approximately 925 pounds of mercury is dependent on a number of factors, including disposal. It is estimated that between 13 and 15 percent of the lamps disposed in the U.S. are either recycled or disposed of as hazardous waste, and 85 to 87 percent are disposed in regular municipal solid waste (MSW).[115,116]. In New Jersey, about 25 percent of MSW goes to incinerators, and the remainder is approximately evenly divided between deposition in out-of-state and in-state landfills.

It is virtually certain that fluorescent tubes disposed in regular MSW break before they reach their ultimate disposal site. The amount of mercury that is released from broken fluorescent lamps (i.e., volatile Hg releases) is the subject of some debate presently. EPA has used a volatilization rate of 6% to model the releases of mercury from fluorescent lamps.[117] However, Erdheim, on behalf of the National Electrical Manufacturers Association (NEMA), has suggested that mercury releases from lamps transported by garbage trucks and from recycling programs

---

[111] Paul Walitsky, Philips Electronics Corp., personal communication, February 28, 2001.

[112] Nesting, David, Paul Walitsky, and Manuel Oomens, 2000, Non-hazardous fluorescent TL lamps, presented at meeting of Illuminating Engineering Society, Washington, DC, July 31, 2000 and in press, *Journal of Illuminating Engineering Society*, 2000.

[113] National Electric Manufacturers' Association (NEMA), 2000, *Environmental Impact Analysis: Spent Mercury-Containing Lamps*, NEMA, Rosslyn, VA.

[114] U.S. Environmental Protection Agency, June 30, 1997. *Mercury Emissions from the Disposal of Fluorescent Lamps - Final Report.* Office of Solid Waste. Washington, D.C.

[115] NEMA, 2000, *Environmental Impact Analysis,* p. 3.

[116] U.S. EPA, 1997

[117] U.S. EPA, 1997.

represents 1% of the mercury in the lamps.[118] Release of a much higher percentage of the mercury in discarded lamps has been suggested by a study for Oak Ridge National Laboratory by Lindberg, et al.[119] These researchers have issued preliminary figures from a Florida landfill study of mercury emissions that indicate mercury emissions from broken fluorescent lamps persist for at least a week and may represent 20% to 80% of the mercury in the lamps.

Preliminary results of a study carried out recently in New Jersey[120] are consistent with the low end of the range reported by Lindberg, et al. In the New Jersey study, used, discarded fluorescent tubes were broken inside a sealed container, and the rate at which the mercury was emitted was measured. Comparison of the emission rate with the reported original mercury content of the tubes indicates that at temperatures ranging from 40° to 85° F, between 15% and 45% of the mercury contained in a broken fluorescent tube will volatilize during a two-week period. The study also found that one-third to one-half of the mercury that escapes from broken tubes is released during the first six hours. It also found that, and shortly after breakage, mercury concentrations in the immediate vicinity of broken tubes are likely to exceed the OSHA workplace exposure limit of 0.1 mg/m^3 as well as EPA's reference concentration of 300 nanograms/m^3. The preliminary results of the New Jersey study are consistent with a preliminary analysis of data collected during the operation of a commercial bulb-crushing system in Illinois, which suggests that between 10% and 20% of the mercury in fluorescent tubes was released during crushing operations.[121] .

If all of the fluorescent tubes discarded in New Jersey break during handling, and if 15% to 45% of the mercury contained in these tubes escapes prior to these tubes' ultimate disposal, the air emission from broken lamps is in the range of 240 ± 125 pounds per year.

A rough materials accounting of the estimated 925 pounds of mercury contained in discarded fluorescent tubes in the year 2000 is presented in the Table titled Materials Accounting of Estimated 925 lbs./yr. Mercury in Discarded Fluorescent Tubes.

---

[118] Erdheim, R. 1997. Letter to Northeast States for Coordinated Air Use Management from R. Erdheim, National Electrical Manufacturers' Association (NEMA). December 4, 1997. Rosslyn, VA.

[119] Lindberg, S. E., K. Roy and J. Owens (Oak Ridge National Laboratory), February 6, 1999. ORNL Sampling Operations Summary and Preliminary Data Report for PaMSWaD-I, Brevard County Landfill. (Publishing agency is not named).

[120] Aucott, M, M. McLinden, and M. Winka, NJDEP, Report in preparation, December, 2000.

[121] Swain, Edward, Minnesota Pollution Control Agency, personal communication, November, 2000.

Table 2

Materials Accounting of Estimated 925 lbs./yr. Mercury in Discarded Fluorescent Tubes

Management method	Portion managed	Pounds Hg per year managed	Short-term release to Environment, lbs./yr.	Explanation of release quantity
Recycled or disposed as hazardous waste	14%	130	trace	emissions controls assumed
Disposed as municipal solid waste (MSW)	86%	795	240	Assumes 100% breakage during waste handling, and partial release of contained mercury[122]
			6	Released via incineration[123]
			<1	Released from landfills[124]
Totals	100%	925	<250	

Sectors Affected

Actions to reduce emissions from lamp breakage in the course of disposal could involve a variety of sectors, including governmental waste management agencies, manufacturers and distributors of fluorescent lamps, waste handlers and recyclers. The actions could also include all those, including large and small businesses, public and private institutions, and residential households, that use and discard fluorescent tubes.

Receiving Media

Mercury contained in fluorescent lamps that are disposed of in landfills and municipal solid waste incinerators can be released from these facilities in the form of air emissions, or in landfill leachate. The amount of mercury entering the environment from discarded lamps, once they reach their ultimate disposal site, is included in the total emissions from these source categories. See Table 2 above.

---

[122] Assumes about 30% of the approximately 720 lbs. entering the MSW stream is released during the two-week period that waste could be in the waste management processing system.

[123] Approximately 25% of the NJ MSW stream, 1.6 million tons, is incinerated in NJ yearly (see separate write-up on MSW combustion). MSW's mercury content is estimated as 2 ppm, which translates to 6400 pounds of mercury going to incinerators. Assuming 25% of the 500 lbs. of mercury not released from discarded tubes goes to incinerators, fluorescent tubes contribute about 2% of this mercury. Thus, about 2% of the yearly mercury emission from incinerators of about 300 pounds can be attributed to fluorescent tubes.

[124] Mercury emissions from NJ landfills are about 30 lbs./yr. It is assumed, as in note above, that 2% of this is contributed by fluorescent tubes.

Mercury released from broken lamps during the estimated one- to two-week period that discarded lamps are present in the waste management system before landfill cover or incineration is considered herein to be a gaseous air emission. Some of the phosphor powder material present inside lamps, to which some mercury binds as the tube ages, could also be released to the environment in particulate form.

Chemical Species

Mercury releases from broken fluorescent lamps may be primarily elemental mercury vapor. Mercury in the phosphor powder is primarily divalent; [125] lamp breakage can cause the powder to separate from the glass and be deposited at the site of breakage.

Recommended Control Opportunities, and Discussion of Costs, Difficulties, Impediments

As discussed above, it is estimated that most of the mercury emissions associated with fluorescent tubes occur when discarded lamps are broken during normal MSW disposal operations, and before the discarded lamps reach their ultimate disposal site. Currently, it is not feasible to prevent lamp breakage if lamps are disposed of in regular MSW. Therefore, at this time, control of mercury releases from fluorescent lamps can be best accomplished by assuring spent lamps are collected and sent to a recycling facility, rather than disposed in the municipal waste stream. To be effective, this recycling system must: 1) store and transport the lamps by means that assure they are not broken before arriving at the recycler's facility, and 2) recycle lamps at a facility that recovers mercury from the glass and aluminum caps as well as the phosphor powder.

Another option for managing discarded tubes may be possible. Because mercury emissions from landfills appear to be very low (see separate write-up on landfill gas), landfills may offer an opportunity for effective sequestration of mercury contained in products, including fluorescent tubes. However, for landfills to be considered as an appropriate disposal site for discarded fluorescent tubes, a system would have to be put in place to prevent breakage of tubes during transport, and to ensure appropriate, safe management of the tubes prior to burial in the landfill. It is unclear at this time whether such a system would be cost-effective when compared with alternative discarded tube management systems, i.e., disposal as hazardous waste and recycling. More data on the relative cost distribution between the collection/transport/handling step and the crushing/reclamation step in fluorescent tube recycling operations might shed light on whether an appropriate discarded tube management system involving landfills could be feasible.

Spot Replacement of HID Lamps

Another method that could contribute to the reduction of mercury releases from spent mercury-containing HID lamps is to assure that only spent lamps are removed from service. Mercury-containing HID lamps should not be removed from service until they have reached the end of

---

[125] Bleasby, Peter, Osram Sylvania Corporation, personal communication, July 11, 2000.

their useful service life. For example, in Paulsboro, New Jersey PSE&G operates a resource recovery facility to assure certain equipment and items removed from service are disposed properly. PSE&G uses this facility to implement a Lighting Residuals Management Program. This program consolidates, segregates and tests high-pressure sodium lamps from street light maintenance operations to limit the premature recycling of these lamps and to assure that spent or out-of-specification lamps are recycled. Other large users of HID lamps within New Jersey should be made aware of the economic and environmental benefits of this program and encouraged to implement similar programs.

Relamping Indoor Spaces for Energy Savings

For linear tubes used indoors, changing large numbers of lamps—and, if appropriate, ballasts—at the same time may be effective in reducing energy consumption and avoiding significant mercury emissions from power plants. Rather than wait for individual lamps to flicker and burn out, and changing them one at a time, many facilities practice "group relamping" because it saves on labor costs as well. Energy savings are greatest when T8 lamps and new electronic ballasts replace older T12s operated with magnetic ballasts. A 34-watt T8 is as bright as a 40-watt T12. (Newer T12s may be 34 watts.) Additionally, many managers find spaces that are overlit as designed; fewer tubes, using even less energy, may be sufficient for the comfort and productivity of people working in the area.

Replacing old magnetic ballasts with electronic ballasts increases energy savings as magnetic ballasts add up to 15 percent additional wattage to the lamp. Electronic ballasts will not flicker or hum. T8 lamps require electronic ballasts to work properly.[126]

Outreach and Education

Major outreach and education efforts, stressing toxicity of mercury, the importance of recycling/reclamation/retirement of mercury, and proper handling procedures for spent lamps, could reduce estimated releases. Use of low-mercury fluorescent lamps, which will also result in a significant decrease in the amount of mercury released from lamp breakage, should be encouraged.

Research, Development, and Monitoring

Until mercury can be eliminated from fluorescent and HID lamps, information should be gathered to assess the number of fluorescent lamps that are disposed in New Jersey annually and the disposal methods used. This data can then be used to target industries and population segments for outreach and education pertaining to recycling and/or proper management of spent lamps.

Because of the potentially large mercury emissions from broken, discarded lamps in New Jersey (estimated herein to be in the range of 100 to 320 pounds per year) more data should be collected on mercury emissions from this source. Included in the data collection effort should be

---

[126] Paul Walitsky, Philips Electronics Corp., personal communication, February 28, 2001.

development of a reliable way to estimate the quantities of discarded lamps managed by the various methods.

Incentives and funding from sources such as the New Jersey Commission on Science and Technology should be provided for research directed toward reducing or eliminating the use of mercury in fluorescent and high-intensity discharge light lamps.

Recommendations

New Jersey should establish a statewide policy for the handling and disposal of fluorescent lamps. This policy should include the following elements:

- Encourage use of low-mercury lamps, beginning with Treasury's procurement policies for state agencies and facilities. Transition to low-mercury lamps, especially low-mercury T8 lamps (some of which contain as little as 3.6 mg mercury) will eventually result in a decrease in the amount of mercury released from breakage, incineration, and landfill disposal. This transition will produce collateral benefits because the T8 lamps consume less energy per lumen, and the energy savings will translate to reduced air emissions of mercury from electricity generation.

- Promote relamping with low-mercury, energy-efficient lamps, including replacement of magnetic ballasts with electronic ballasts, in order to reduce mercury emissions from power plants.

- Promote appropriate management of discarded mercury-containing lamps. Currently, such appropriate management includes only recycling and disposal as hazardous waste. It is possible that other management systems could be developed in the future that would include landfills as the ultimate disposal sites, provided that sufficient safeguards were in place to prevent tube breakage prior to burial, and provided that monitoring data continues to indicate very low mercury releases from landfills. When setting up or supporting mercury recycling programs, specify recycling technology that reclaims mercury from all parts of the lamp, including the glass.

- Following the recommendations of DEP, support classification of discarded fluorescent lamps as universal waste. Such classification will help minimize costs of managing discarded lamps appropriately. Consider adoption of further rules or legislation that would require at least some of the larger CESQGs to recycle discarded lamps or dispose of them as hazardous waste.

- Educate waste management contractors and staff about the hazards of handling broken tubes or any materials contaminated with mercury. Since mercury from broken lamps is initially released rapidly, it is important to minimize exposure of workers to broken lamps.

- Prohibit disposal at incinerators. Despite current effective controls on mercury emissions from incinerators, emissions could be reduced further by keeping mercury-containing wastes, including discarded fluorescent tubes, out of the waste stream.

- Encourage removal from service of spent mercury-containing HID lamps only. Mercury-containing HID lamps should not be removed from service until they have reached the end of their useful service life.[127] Note that this recommendation does not apply to fluorescent tubes used indoors.

Recommendations

- Acquire better data on emissions of mercury from breakage of discarded lamps.
- Acquire better data on quantities of lamps disposed, by management method.
- Provide incentives and funding for research to reduce or eliminate mercury in lamps.

---

[127] For example, in Paulsboro, New Jersey PSE&G operates a resource recovery facility to assure certain equipment and items removed from service are disposed properly. PSE&G uses this facility to implement a Lighting Residuals Management Program. This program consolidates, segregates and tests high-pressure sodium lamps from street light maintenance operations to limit the premature recycling of these lamps and to assure that spent or out-of-specification lamps are recycled. Other large users of fluorescent and HID lamps within New Jersey should be made aware of the economic and environmental benefits of this program and encouraged to implement similar programs.

Industrial and Commercial Sources Not Elsewhere listed

Identification and Description of Source

It is possible that significant quantities of mercury are released from unknown sources. If such sources exist, facility level materials accounting data may soon be available to identify these sources as a result of recently adopted lower reporting thresholds for mercury and other Persistent Bioaccumulative Toxic (PBT) substance. This lower threshold should also help refine previously collected data for other sources mentioned elsewhere in this report. This section will discuss mercury information available from both facility level *materials accounting* and *inventory* reporting.

Facility Level Materials Accounting Data

Mercury and mercury compounds are listed on the federal Emergency Planning and Community Right to Know Act (EPCRA) Section 313 toxic chemical list, Toxic Release Inventory (TRI). Any New Jersey facility that manufactures or processes more than 25,000 lbs./yr. or otherwise uses more than 10,000 lbs./yr. of a listed hazardous substance is required to file a TRI report (Form R) with EPA with a copy to NJDEP quantifying the amount of material annually released to the environment. The manufacturing sector of the economy, which includes facilities in Standard Industrial Classification (SIC) codes 20 through 39, have been covered by TRI reporting since the programs inception in 1987. The Environmental Protection Agency expanded the scope of TRI reporting in 1997 to cover seven new industry sectors including metal mining (SIC code 10), coal mining (SIC code 12), electrical utilities that combust coal and/or oil (SIC codes 4911, 4931, and 4939), Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste treatment and disposal facilities (SIC code 4953), chemicals and allied products wholesale distributors (SIC code 5169), petroleum bulk plants and terminals (SIC code 5171), and solvent recovery services (SIC code 7389). These newly covered facilities were required to report releases above the reporting threshold beginning July 1999 for reporting year 1998. There are no metal or coal mining facilities (SIC 10 and 12, respectively) currently operating in New Jersey.

In New Jersey, any facility required to file a federal TRI report is required to submit a Release and Pollution Prevention Report (RPPR) to the Department's Community Right to Know (CRTK) Program and is also required to perform pollution prevention planning. The notable exception is SIC code 7389 (solvent recovery services) which is not covered under the New Jersey Rules. Any facility which files at least one federal Form R is required to submit an RPPR for all TRI toxic substances which are manufactured, processed or otherwise used in excess of 10,000 lbs./yr. In addition to the release and off-site transfer data captured by the federal Form R, the Release and Pollution Prevention Report also collects facility level throughput data (annual quantities manufactured, consumed, brought on site, recycled on site and off site, shipped as or in products, as well as the amount generated as production related waste, also known as nonproduct output or NPO). Any New Jersey facility submitting an RPPR is required to develop a Pollution Prevention Plan designed to reduce the quantity of TRI substances used at the facility and or generated as nonproduct output. Covered facilities are also required to set five-year reduction goals and to annually report progress made toward reaching the facility level five-year reduction goals.

While it is known that New Jersey businesses use and release mercury to the environment, very little data is available since few facilities exceed the 10,000 lbs./yr. reporting threshold. In December 1998, the Mercury Pollution Task Force provided NJDEP with an interim recommendation requesting that the Department amend its rules to lower the throughput reporting threshold of mercury from 10,000 lbs./yr. to 100 lbs./yr. Lowering the reporting threshold to 100 lbs./yr. would have provided the Department with more refined estimates regarding mercury usage and environmental releases. The Department had the statutory authority to lower the mercury reporting threshold to 100 lbs./yr. and began moving forward with the Task Force recommendation. However, the point soon became moot when EPA proposed its Persistent Bioaccumulative Toxic (PBT) substance rule in January 1999 and adopted an even lower 10 lbs./yr. reporting threshold for mercury later that year. The federal TRI amendments were immediately adopted by reference by the New Jersey Community Right to Know and Pollution Prevention Programs. Covered New Jersey facilities must submit Form Rs and RPPRs on July 1, 2001 reporting mercury throughput and release data for calendar year 2000 at the 10 lbs./yr. reporting threshold.

As a result of the lower threshold for mercury and mercury compounds, New Jersey will have a better understanding of the use and fate of mercury in the environment. In addition, any facility reporting mercury or mercury compounds to the CRTK program will also be required to perform pollution prevention planning. It is hoped that the pollution prevention planning process will assist facilities in finding ways to reduce or eliminate mercury use and releases.

Facility Level Inventory Data

New Jersey's Worker and Community Right to Know Act also requires reporting of inventories of environmental hazardous substances, including mercury and a number of mercury compounds, from thousands of covered industrial, commercial, and institutional facilities on the Community Right to Know Survey[128]. This information provides clues as to how and where mercury may be used throughout the State. These data were reviewed to assess the amounts of mercury and mercury compounds present at reporting sites. Because the CRTK Survey requires reporting of quantities by the use of inventory range codes (e.g., code "09" is used for quantities less than one pound, code "10" for quantities from 1 to 10 pounds, code "11" for quantities from 11 to 100 pounds, etc.), actual quantities must be estimated. With the assumption that the median quantity of each range is the actual quantity represented by a code, totals for the various chemicals reported can be estimated. The 1991 CRTK Survey database indicates that several hundred facilities had on site a combined inventory of several hundred thousand pounds of mercury and various mercury compounds, including mercuric iodide, phenyl mercuric acetate, mercuric nitrate, mercuric sulfate, mercuric chloride, and mercury fulminate.

A review of 1999 CRTK Survey data, reflecting the higher 500 lbs./yr. threshold, was also conducted. Eight facilities were identified reporting mercury and or mercury compounds with an

---

[128] NJDEP/BCRIP

annual inventory of between 10 and 100 pounds each, seventeen facilities reporting an inventory between 100 and 1,000 pounds, and three facility with inventories between 1,000 and 10,000 pounds. Two hospitals reported annual mercury inventories on the 1999 CRTK Inventory Survey in quantities ranging from 100 to 1,000 pounds. Six educational institutions reported annual mercury or mercury compound inventories including three elementary/secondary schools, two universities, and one technical school. Most of these educational institutions reported inventories ranging from one to ten pounds with the notable exception of one university reporting an annual inventory between 100 and 1,000 pounds. Three glass manufacturers reported an elemental mercury inventory ranging from 10 to 1,000 pounds, perhaps used as a calibration tool in the manufacture of volumetric laboratory glassware. Two scrap and waste material facilities each reported annual mercury inventories between 100 and 1,000 pounds. Mercury contained in scrap metal may be a potential source of contamination for iron and steel manufacturers as discussed in the *"iron and steel manufacturing and ferrous scrap processing"* section of this chapter.

The presence of these large quantities of mercury and mercury compounds on sites suggests that large uses of these substances may occur. Such large uses, if they occur, could be accompanied by large releases to the environment.

Quantity and Estimated Uncertainty

The PBT Rule amended federal TRI and New Jersey RPPR reporting requirements and significantly lowered the reporting threshold for certain PBT substances, including mercury and mercury compounds. The final rule took effect December 31, 1999 for reporting year 2000. Under the new federal rules any facility which manufactures, processes or otherwise uses mercury or mercury compounds in excess of 10 lbs./yr. is required to file a TRI report. Release reporting requirements were also changed to require quantification of any release to the level of significant figures that the measurement techniques support. For mercury, releases will now be reported at or below one pound per release incident. The rules also eliminated the de minimis reporting exemption for PBT substances. Under the old rules facilities were allowed to disregard concentrations of hazardous substances contained in mixtures if a substance was present in the mixture at less than one percent. If the substance was listed as an OSHA carcinogen the de minimis level was reduced to less than 0.1 %. Depending upon the concentration of mercury in the raw material, facilities which annually throughput large quantities of raw material (e.g. iron and steel manufacturers, petroleum refiners and coal fired utilities) have the potential to release mercury into the environment in excess of the 10 lbs./yr. reporting threshold. Eliminating the de minimis limit will now capture these releases that would have otherwise gone unreported.

The 1991 CRTK Inventory Surveys reflect all mercury use by reporting facilities, since there was no reporting threshold in place at the time. A 500 lbs./yr. inventory reporting threshold was introduced in 1994 limiting the amount of information collected for mercury used or stored in small quantities. Some facilities continue to report quantities of mercury and other compounds on the CRTK Survey below the 500 lbs./yr. reporting threshold. The CRTK Survey requires reporting of quantities by the use of inventory range codes (e.g., code "09" is used for quantities less than one pound, code "10" for quantities from 1 to 10 pounds, code "11" for quantities from 11 to 100 pounds, etc.) rather than reporting the actual quantity present at the facility. The use of range codes makes it difficult to precisely estimate actual quantities stored at New Jersey facilities. However, with the assumption that the median quantity of each range is the actual quantity represented by a code, totals for the various chemicals reported can be estimated.

Sectors Affected

Any sector referenced above subject to federal TRI and New Jersey RPPR reporting and Pollution Prevention Planning requirements may potentially be affected by the lower mercury reporting threshold. The Department will have a better understanding of which facilities are affected when the RPPRs are reviewed in July 2001. Potentially affected facilities include those that burn large quantities of fuel oil and or coal, including ten coal fired electric generating utilities and six petroleum refineries in the state. Other potentially affected facilities include six iron and steel manufacturers, at least two aluminum processors, and electronic equipment manufacturers in the state. Facilities required to report CRTK Surveys of quantities of mercury and mercury compounds greater than 500 pounds are those that fall into the standard industrial classification (SIC) codes shown in Table 1.

Table 1.

Standard Industrial Classification Codes: New Jersey Employer Groups and Activities Subject to Hazardous Substances Reporting

SIC Code	ACTIVITY
07*	AGRICULTURAL SERVICES
20 - 39	MANUFACTURING ESTABLISHMENTS
45*	TRANSPORTATION BY AIR
46	PIPELINES, EXCEPT NATURAL GAS
47*	TRANSPORTATION SERVICES
48*	COMMUNICATIONS
49	ELECTRIC, GAS, AND SANITARY SERVICES
50*	WHOLESALE TRADE - DURABLE GOODS
51*	WHOLESALE TRADE - NONDURABLE GOODS
55*	AUTOMOTIVE DEALERS AND GASOLINE SERVICE STATIONS
72*	PERSONAL SERVICES
75*	AUTOMOTIVE REPAIR, SERVICES, AND GARAGES
76*	MISCELLANEOUS REPAIR
80*	HEALTH SERVICES
82*	EDUCATIONAL SERVICES
87*	ENGINEERING, ACCOUNTING, RESEARCH, MANAGEMENT, AND RELATED SERVICES
91 - 96	PUBLIC ADMINISTRATION - All State, County, and Local Governments[3]

*** indicates only a portion of the major group is covered**

Receiving Media

Receiving media are unknown at this time, but include air, water, land, landfills and products in general use throughout the state.

Chemical Species

Chemical species include elemental mercury and various mercury compounds, including mercuric iodide, phenyl mercuric acetate, mercuric nitrate, mercuric sulfate, mercuric chloride, and mercury fulminate.

Reduction Options and Associated Costs and Impediments

Specific reduction options cannot be specified at this time. New Jersey's Pollution Prevention Rule requires covered facilities to prepare Pollution Prevention Plans to reduce their use and nonproduct output of covered substances, including mercury and its compounds. The Rule also requires facilities to set five-year use and nonproduct output reduction goals. However, implementation of pollution prevention options identified in Pollution Prevention Plans is optional, as are facility level use and nonproduct output goals. Pollution prevention options may range from inexpensive administrative controls such as implementing best management practices and spill and leak prevention measures to more expensive process modification options requiring the installation of new equipment.

Research, Development, and Monitoring Options

It is imperative that the Department review the Release and Pollution Prevention Reports and the Toxic Release Inventory as soon as possible after July of 2001, when the next iteration of these reports is received with the new 10 lbs./yr. threshold for mercury. Posting of facility level five-year reduction goals on the Department's web site will help make this information readily available to the community and enhance public awareness of mercury use in New Jersey.

Outreach and Educational Options

The Department should continue its outreach to covered facilities, carried out by the Pollution Prevention and CRTK Programs, to ensure proper and accurate reporting.

Recommendations

- The Department should continue to apply pressure on covered facilities to develop and implement quality Pollution Prevention Plans pursuant to the New Jersey Pollution Prevention Act, in order to achieve meaningful mercury use and release reductions.
- The Department should review the Release and Pollution Prevention Reports and TRI inventory as soon as possible after July 1, 2001, and use these reports as well as other sources to gain better a better understanding of mercury releases from these sectors.
- The Department should increase enforcement activities to ensure that all facilities which may potentially exceed mercury reporting thresholds for the RPPR and/or CRTK Survey have indeed reported.
- The Department should allocate sufficient resources to ensure enforcement activities and data

processing and analysis are completed in a timely fashion.

- The Department should post five-year facility level use and nonproduct output reduction goals on the Department's web site.
- The Department and EPA should continue outreach to covered facilities to promote pollution prevention.

Iron and Steel Manufacturing and Ferrous Scrap Processing

Identification and Description of Source

In New Jersey, there are three facilities that produce steel by melting scrap in electric arc furnaces and three facilities that produce cast iron from melting scrap in cupolas (vertical furnaces). The air pollution permit for each facility includes a mercury limit. In some cases these limits have been exceeded resulting in ongoing enforcement actions. Stack tests conducted pursuant to permit conditions at five of the six facilities have demonstrated that mercury emissions occur in the range of 1000 pounds per year.

In the three cupola furnaces and one of the electric arc furnaces, coke is mixed with metallic scrap to serve as a reducing agent to remove oxides. This coke is manufactured by heating high-grade bituminous coal (low sulfur and low ash) to around 1925° F in an enclosed oven chamber without oxygen. Mercury contained in the feed coal is probably driven out by the high temperatures of the coke manufacturing process. Therefore, it is likely that the mercury emitted by these facilities comes from the feedstock ferrous scrap.

The scrap includes recycled metals from discarded motor vehicles and home appliances, and waste metals from demolished building structures. It is known that mercury is used in a number of items that, when discarded, are likely to find their way into metallic scrap. For example, in the U.S. about 10 tons per year of mercury was used through the mid-90s in tilt switches (e.g., in trunk lights) and in anti-lock braking systems in automobiles. Mercury has also been extensively used in gas pressure regulators, switches and flame sensors in appliances.[129] Mercury switches are still used by some manufacturers, although a planned phase out by 2002 is reported.[130] Mercury is also used extensively in residential thermostats and in industrial equipment including thermostats, relays and other switches and control devices, and in measuring devices.

Existing stocks of such items, based on reported use quantities and estimates of service lives, are likely to be surprisingly large (see write-up on mercury-containing products in general use). For example, a recent study indicates there are 172-200 tons of mercury in switches in automobiles presently on the road in the U.S.[131] With 3% of the U.S. population, and somewhat more than 3% of the U.S. vehicle fleet, there would thus be between 10,000 and 12,000 pounds of mercury in switches in New Jersey's motor vehicle fleet alone. Since the average age of automobiles on the road is approximately 9 years,[132] it can be assumed that approximately 10% of the motor vehicle fleet is discarded yearly, implying that more than 1000 pounds of mercury from automobiles in New Jersey enters the scrap processing system each year.

---

[129] Cain, Alexis, USEPA Region V, Contamination of Scrap Metal with Mercury: A Potentially Significant Source of Mercury Emissions, presented at the conference *Coordinating Mercury Reduction Programs: A Meeting of National and Local Government Officials*, Baltimore, MD, March 20-21, 2000.

[130] Corbett, Thomas, New York Department of Environmental Conservation, personal communication, July, 2000.

[131] Ecology Center, Great Lakes United, and U. of Tennessee Center for Clean Products and Clean Technology, *Toxics in Vehicles: Mercury,* January 2001, p. 7.

[132] U.S. Department of Transportation, 1998, National Highway and Traffic Safety Association, U.S. DOT, http://www.nhtsa.dot.gov, Washington, D.C.

It is important to note that while use of mercury switches in vehicles has declined significantly in recent years (62 to 77 percent since 1996), mercury use in anti-lock braking systems has increased over the same period by at least 130 percent and perhaps as much as 180 percent.[133]

Ferrous scrap is processed by a number of different industries and types of facilities. Discarded automobiles, for example, are first handled by wreckers who tow vehicles to storage areas. From there, high-value vehicles are transferred to any of several hundred automobile dismantlers operating in the state. When the useful parts, cast-iron parts, tires, liquids and other items have been removed by the dismantlers, the hulks are crushed, and then transported to one of several shredders operating in New Jersey and the surrounding area. Discarded automobiles of lower value, such as older vehicles and totaled wrecks, may go directly to a shredder. Shredding reduces the hulk to fist-sized pieces of metal. Other discarded metal items, including appliances, demolition debris, etc. also enter the scrap processing system at various points. Ultimately, the processed scrap is shipped out of state or used as feedstock for one of the state's iron or steel manufacturers. Some of the feedstock used by New Jersey manufacturers comes from out of state as well.

Mercury may be released to the environment at various points in the scrap processing system. For example, mercury-containing items such as thermostats and switches may not survive a shredding process intact.

Quantity and Estimated Uncertainty

Stack test results are varied, but indicate significant emissions from the iron and steel manufacturing sector. Calculations using the permitted mercury emission for one facility, and the reported emission rates based on permitted hours of operation and the most recent stack tests for the other five facilities, gives an estimate in the range of 1000 lbs. of mercury per year. A spreadsheet available from the Department provides a summary of these data. The limited number of tests per facility and the lack of test results for one facility makes this estimate uncertain. However, this result corresponds with national data indicating that mercury air emissions from electric arc furnaces total 15.6 metric tons per year in the U.S., of which mercury from automobiles is likely the single largest contributing source.[134]

There are also some mercury emissions likely associated with the shredding process, and with the dismantling of automobiles and other discarded items. A mass balance of mercury at a mid-western electric arc furnace indicated that the mercury inputs to the facility were apportioned to outputs as follows: stack emissions, 31%; furnace silo dust; 49%; shredder fluff residue, 18%; and on-site auto shredder emissions, 2%[135].

Sectors Affected

---

[133] Ecology Center, 2001

[134] Ibid., p. 36.

[135] Cain, Alexis, USEPA

The six large industrial facilities in this category would be affected by implementation of reduction requirements.

Receiving Media

The primary receiving medium is believed to be air, from stack emissions at the facilities. There may be some mercury runoff to water and land contamination from outdoor scrap piles. There may be health effects to on-site workers from exposure to mercury.

Chemical Species

The species of the emissions and suspected emissions are unknown, but, because the mercury used in switches, etc. is elemental, and because there is no direct combustion of the mercury-containing items during the steel and iron manufacturing processes, the emissions are probably also elemental.

Reduction Options and Associated Costs and Impediments

Reducing mercury emissions from iron and steel manufacturers will undoubtedly require a multi-media, multi-sector pollution prevention approach, including removal of mercury from feedstock scrap. Such removal will necessitate: 1) elimination of mercury-added parts from new cars; and 2) removal of mercury switches from existing cars when they are dismantled or prior to shredding. Scrap management becomes the focus of source reduction efforts.

However, scrap processors report significant difficulty in obtaining information from automakers about the exact location of the switches in trunks and hoods. Auto manufacturers should take responsibility for facilitating removal of mercury from vehicles they have produced, both by providing information to dismantlers and scrap processors, and, if necessary, by providing resources to facilitate removal. Unfortunately, the regulatory burden at this time is falling on the iron and steel manufacturers and, to a lesser extent, on scrap yards where mercury spills are reported.

Analogous to New Jersey's Municipal Waste Incinerator rules, a performance standard for iron and steel manufacturers could be designed to reduce mercury emissions through a combination of aggressive pollution prevention, source separation, and available controls.

Periodic testing should be required. Frequency of testing should depend on the mercury emission level. Prior to setting a specific mercury emission limit, the Department should require testing of carbon injection to determine its effectiveness for iron cupolas and steel furnaces. Realistically, air pollution controls at iron and steel manufacturing facilities are likely to continue to be necessary in addition to mercury separation. The current use of baghouse air pollution control devices on one of the cupola furnaces and all three of the electric arc furnaces makes carbon injection a relatively low capital cost option for four of the six facilities. The two cupola furnaces with scrubbers would need to rely on scrap management or evaluate measures to remove mercury switches, or both. Scrubbers do remove some forms of mercury, but are less effective than carbon injection with baghouses. Measures to oxidize mercury prior to a scrubber may substantively increase the mercury removal effectiveness of scrubbers. Removal of mercury from the scrubber residue and liquor would be needed.

Prior to implementation of stringent limits, however, iron and steel manufacturers, auto dismantlers, and scrap processors might be provided time to work with auto manufacturers to develop cooperative programs to reduce mercury in scrap. In two USEPA regions (Region 2 and Region 5), a "bounty" program for mercury is under discussion, based on the premise that if mercury had greater value it would be removed from scrap before ever reaching the smelters. Such a bounty, to be paid to dismantlers or shredders, could be funded by the auto manufacturers and/or iron and steel manufacturers. A pilot bounty program, including a significant research component, should be tested in an interstate region, since scrap autos are a highly movable commodity.

Recovery and recycling or retirement of mercury in vehicles would be greatly facilitated by designation of mercury-containing switches as Universal Waste in New Jersey and other states participating in a bounty program.

Because non-mercury-containing replacement switches are readily available for vehicle convenience lighting, state government and other fleet operators could replace mercury switches while cars are still in service. Purchasing specifications for new cars could require that mercury switches be exchanged for non-mercury switches before cars are delivered.

Research, Development, and Monitoring Options

Testing of carbon injection should be performed to determine its effectiveness for iron cupolas and steel furnaces. Also, measures to increase the effectiveness of scrubbers should be evaluated.

A pilot bounty program should be designed to yield data about the optimum amount of the bounty, and the quantities of mercury that can be recovered from various points along the auto dismantling/scrap processing line.

More data are necessary on possible mercury releases associated with scrap metal shredding and other processing activities.

Outreach and Educational Options

The importance of removing mercury-containing switches and other items should be communicated to automobile dismantlers and others in the recycled metal processing industry, fleet managers, governmental officials responsible for regulating motor vehicles, and the general public.

Recommendations

- The federal government should require the rapid phase out of the use of mercury-containing products in new motor vehicles. Following the lead of other states, New Jersey should consider banning the sale of vehicles containing mercury products.

- Implement a phased strategy to reduce mercury contamination of scrap through elimination and separation measures. If, after a 3-year period, the source reduction measures do not achieve emission reduction goals, require the installation of air pollution control.
- Ensure that measures to reduce mercury contamination of scrap are developed through a cooperative process involving government agencies and affected industries, including automobile manufacturers, automobile recyclers, and those who crush, shred, or otherwise process scrap metal.
- Designate mercury switches as a Universal Waste in New Jersey.
- Require testing of carbon injection to determine its effectiveness for iron cupolas and steel furnaces. Where scrubbers are used, require testing of effectiveness and measures to improve effectiveness.
- Require periodic stack testing with the frequency depending upon the mercury emission level.
- Educate auto dismantlers, shredders, fleet managers, vehicle service facilities, and other relevant audiences about the importance of removing mercury from vehicles before they are processed into scrap.
- Determine through measurements whether scrap processing operations including shredding release significant quantities of mercury to the environment.

Mercury-Containing Products in General Use

Identification and Description of Source

Mercury has been and is used in a wide variety of products, and is also a contaminant in materials used in commerce, including fossil fuels and their derivatives. Commonly used consumer products that contain mercury include some types of batteries, fluorescent lamps, thermostats, switches, and other measuring and control devices. Some of the mercury used in products or inadvertently included with products and other items in commerce can escape to the environment. Such escapes can be the result of spills or breakage. For example a broken thermometer will typically result in a small quantity of elemental mercury being dispersed in the immediate environment of the breakage. Historical uses of some products, such as mercury-containing pesticides, have resulted in direct releases to the environment.

This source category addresses mercury released from products due to breakage and subsequent mercury spillage during use, and mercury released from products that break and spill mercury during disposal or during recycling. Releases from products that occur after mercury-containing items have been deposited at a disposal site, transferred to wastewater, or re-introduced to commerce as recycled items (e.g., scrap metals) are not included in this category. Such releases are included in other reports, including the reports addressing releases from municipal solid waste incineration, wastewater treatment, sludge management, landfills, broken fluorescent tubes, laboratory uses, iron and steel manufacturing, cultural uses, and others.

Quantity and Estimated Uncertainty

The quantity of mercury volatilized from products in use and during the waste disposal process can be estimated from a calculation based on a series of assumptions, estimates, and physical data for mercury. This calculation is presented in detail in Appendix B.

Combining the estimates from releases during waste handling and the mid-point of estimated releases due to in-service spillage as described in Appendix B leads to an overall estimate from this source category of approximately 300 pounds per year. Because of the numerous assumptions and approximations used to derive this estimate, an uncertainty of at least ± 75% is assigned.

Sectors Affected

All sectors using mercury-containing products, or managing such products during disposal and recycling are potentially affected.

Receiving Media

The receiving medium for mercury volatilizing from products during use or disposal is the air. Much of the mercury in products winds up in landfills, where it appears to be sequestered to a large degree, based on available data. Some mercury in products may be released to water and land as well. See separate write-ups addressing releases from municipal solid waste incineration, wastewater treatment, sludge management, landfills, broken fluorescent tubes, laboratory uses, iron and steel manufacturing, cultural uses, and others.

Chemical Species

The procedures described herein assume the main mercury species subject to volatilization is elemental mercury. Other species of mercury may be released to water or land or sequestered in landfills.

Reduction options and associated costs and impediments

Household batteries

Thanks to federal mercury content law, mercury may no longer be intentionally introduced into household batteries, except for button cell batteries, which may contain up to 25 mg. Foreign battery manufacturers appear to be following U.S. guidelines. However, older batteries still in the possession of consumers can contain 1 to 2 percent mercury. Preventing pollution from these batteries will rely on battery collection and recycling until old batteries are no longer in the waste stream.

Batteries are Universal Waste in New Jersey. This legal designation facilitates collection and recycling by large quantity generators.

Recommendations

- Support legislation requiring labeling of button batteries with mercury content.
- Support legislation banning disposal of batteries in trash incinerators (source separation).
- In state purchasing contracts, require that battery vendors take back spent batteries for recycling.
- Support and encourage collection and recycling of batteries by households and small businesses (exempt from the Universal Waste Rule).

Electrical lighting components

Fluorescent lamps, including linear tubes and compact fluorescent lamps, are discussed in the "Fluorescent lamps" section of this chapter.

Fever thermometers

According to EPA's 1992 projections, more than more than 900,000 mercury fever thermometers enter New Jersey's municipal solid waste stream each year, accounting for more than 1,000 lbs. of mercury. Each mercury fever thermometer contains about one half gram of mercury. Acceptably accurate digital, non-mercury thermometers and heat-sensitive "temperature strips" are readily available. Numerous municipalities and special districts around the nation have initiated thermometer exchange programs that collect mercury thermometers for hazardous waste disposal, and distribute digital models. Several large grocery and drug store chains have voluntarily stopped selling mercury fever thermometers; a bill in the New Jersey legislature would ban their sale in the state.

Recommendations

- Support legislation banning the sale of mercury fever thermometers in New Jersey.
- Fund, support, and encourage local thermometer exchange programs.
- In state purchasing contracts, specify non-mercury thermometers in applications where digital alternatives are feasible.
- Work with small and large retailers to obtain voluntary agreements to stop selling mercury thermometers and to distribute educational materials to customers.
- Provide public education about the hazards of mercury spills from broken thermometers, safe cleanup methods, and the importance of taking mercury thermometers to a household hazardous waste collection event *before* they break.
- Educate physicians about the importance of not giving mercury thermometers to patients to take home.

Thermostats

The 1997 in-use inventory of mercury thermostats in the state can be estimated at approximately 2 million thermostats, accounting for 17,670 pounds of mercury (based on an average 4.1 grams per thermostat)[136]. Discarded thermostats (including thermostats in demolition waste) contribute more than 600 pounds of mercury to New Jersey's municipal solid waste annually. Mercury-containing thermostats are Universal Wastes in New Jersey, a designation intended to facilitate proper (hazardous waste) disposal or mercury recycling by large quantity generators (more than 100 kg [about 220 lbs.] of hazardous waste per month). However, one may assume that most heating contractors and plumbers who install or replace thermostats are unlikely to qualify as large generators. As a number of states move towards banning sale or solid waste disposal of thermostats, Honeywell and other thermostat manufacturers initiated a multi-state take-back program, the Thermostat Recycling Corporation (TRC) in 1998. Unfortunately, the program has never been promoted effectively in New Jersey. In all of 2000, only 354

---

[136] Northeast States and Eastern Canadian Provinces Mercury Study, A Framework for Action, February 1998.

thermostats, accounting for 2.7 lbs. of mercury, were collected at the ten New Jersey locations listed by TRC.[137]

Digital thermostats containing no mercury are the choice of many contractors, although mercury thermostats continue to be sold, especially to the do-it-yourself home repair market. A survey of retailers shows that mercury thermostats are often less expensive and more user-friendly than programmable electronic thermostats which do not contain mercury, although programmable thermostats may have energy conservation advantages.

The industry estimates the life of a mercury thermostat at between 30 and 40 years. Therefore, between 2 and 3 percent of all thermostats may be expected to be retired annually.

Recommendations

- Propose and support legislation banning the sale of mercury-added products, including thermostats, for which acceptable non-mercury substitutes are available.
- Propose and support legislation banning mercury-containing thermostats from MSW or demolition waste disposal.
- In state purchasing and construction contracts, specify all-digital thermostats and require contractors to remove and recycle thermostats containing mercury.
- Pressure the National Electrical Manufacturers' Association (the trade group that operates TRC) to promote thermostat recycling effectively in New Jersey.
- Educate heating/air conditioning contractors and plumbers about the Universal Waste Rule and the importance of recycling thermostats containing mercury through TRC.
- In partnership with hardware stores, educate do-it-yourselfers about environmentally preferable digital thermostats and the importance of recycling mercury thermostats through household hazardous waste programs.

Dental uses of mercury

See the separate section on dental office waste in this chapter.

Mercury light switches

According to EPA's 1992 projections, discarded mercury-containing household switches accounted for 114 lbs. of mercury in New Jersey municipal solid waste in 2000. Like thermostats, mercury light switches (wall switches) generally enter the waste stream during remodeling or demolition of homes, offices, and commercial buildings.

---

[137] http://www.nema.org/government/environment/results2000.html

In general, silent light switches contain mercury tilt switches that have between 2 and 3.5 grams of mercury. Alternatives include hard-contact switches, solid-state switches, electro-optical switches, and a number of types of sensors.
As with thermostats, control of this source depends upon effective education of building and demolition contractors.

Recommendations

- Propose and support legislation banning the sale of mercury-added products, including light switches, for which acceptable non-mercury substitutes are available.
- In state demolition and construction contracts, specify non-mercury light switches. Require contractors to remove and recycle switches containing mercury.
- Educate building and demolition contractors about the importance of careful removal and proper disposal of mercury switches.
- In partnership with hardware stores, educate do-it-yourselfers about the hazards of mercury and the importance of recycling old switches and replacing them with non-mercury alternatives.

Research, Development, and Monitoring Options

Monitoring of the inlet stack gas mercury concentration at all New Jersey MSW incinerators, and monitoring of the total mercury concentration in the ash at two MSW incinerators (Warren County and Essex County) should continue. The data resulting from these monitoring efforts can be used to estimate the concentration of metals in MSW to determine if levels are declining, as expected due to minimization efforts and disposal trends. Current testing protocols should be fully assessed to determine if they are comprehensive.

Outreach and Educational Options

Educating the consumer on the importance of the proper post-consumer-use management of mercury-containing products is recommended. This may be done as previously mentioned through product information. However, the Department may want to consider informing and educating consumers by the use of general awareness publications and/or via the Department's web page.

Non-Ferrous Metals, Including Aluminum and Aluminum Scrap Processing

Identification and Description of Source

There are several facilities in New Jersey that produce non-ferrous metals including aluminum and associated products. At least two of these facilities are believed to use recycled aluminum as a feedstock and to process this material using heat. Based on the large mercury emissions from iron and steel manufacturing facilities which also process recycled metals (see separate write-up elsewhere in this document), contamination of recycled metals with mercury is suspected. Since mercury tends to preferentially amalgamate with aluminum rather than ferrous metals, mercury contamination in the recycled metals stream might tend to be associated more with aluminum than ferrous metals. Therefore, it is possible that facilities that process recycled aluminum using heat have mercury emissions.

Quantity and Estimated Uncertainty

As of May 2001, no stack testing for mercury had been performed at these New Jersey facilities. Emission quantities are unknown. Emissions quantities could possibly be in approximately the same range as emissions from iron and steel manufacturers in New Jersey. An approximate estimate in the range of 1000 pounds per year is offered until data are available.

Sectors Affected

The several facilities that process aluminum and suppliers of recycled aluminum could be affected.

Receiving Media

The receiving medium is expected to be air.

Chemical Species

Species of emissions are unknown. If mercury is released during melting of recycled aluminum, it is likely that most of it is elemental.

Reduction, Outreach, and Education Options and Associated Costs and Impediments

These are unknown at this time. Practices could include education and outreach toward metal processors where separation efforts (removing mercury containing switches, etc.) would result in decreased mercury in the feedstock. Costs may include additional labor. Capture of mercury released from mercury amalgamated with aluminum would require pollution control devices. Carbon adsorption/carbon injection might be an option.

Research, Development, and Monitoring Options

The USEPA has awarded a grant for a NJDEP pilot project which will include stack testing at a small number of facilities. The project will seek to assess and provide quantities of emissions, including mercury. If data collection proves successful, the results from the project will be used to refine the inventory for this source.

Recommendations

- Complete pilot project testing emissions from New Jersey facilities.
- Once emissions are identified, review inventory and if appropriate, propose emission reduction options.

Painted Surfaces

Identification and Description of Source

Inorganic mercury compounds of very low solubility were formerly used as additives in marine coatings and paints to prevent fouling of boat hulls by bacteria and other marine organisms.. This use had largely been discontinued by the mid-70s,[138] with substitution of organotin compounds. Emissions from this source are believed not likely to be significant in New Jersey today since the use ended so long ago, and are not considered further in this report.

A related but different use of mercury compounds in paint was common until the early 1990s and is examined in more detail herein. This use was the addition of phenyl mercuric acetate (PMA) and similar compounds to water-based paints. These were added to prolong shelf-life by controlling bacterial fermentation in the can and to retard fungus attacks upon painted surfaces under damp and humid conditions. In July 1990, partly in response to an incident in 1989 in Michigan when a 4-year old boy suffered mercury poisoning after mercury-containing paint was applied to the interior of his home,[139] all registrations for mercury biocides used in paints and coatings, except for PMA, were voluntarily cancelled by the registrants. In May 1991, EPA announced the voluntary cancellation of the remaining PMA registrations which were for exterior paints and coatings.[140] Several studies had indicated that when mercury-containing coatings and paints were applied, the painted surfaces released elemental mercury to the air.[141,142]

Quantity and Estimated Uncertainty

Large quantities of PMA and other organic mercury-containing biocides were used in the U.S. until 1990.[143] Apportioning the U.S. quantities to New Jersey, assuming that New Jersey accounted for about 3% of U.S. use based on population, indicates that approximately 15,000 pounds of mercury was used in paint applied in New Jersey each year from the mid-60s until 1991.

Estimating the temporal pattern of mercury releases from surfaces to which this paint was applied requires an estimate of the half-life of the mercury in the painted surface. One estimate

---

[138]. U.S. Department of Commerce, Bureau of Mines, Various years, *Minerals Yearbook*, U.S. Government Printing Office, Washington, D.C.

[139]. Beusterien, Kathy, R. Etzel, M. Agocs, G. Egeland, E. Socie, M. Rouse, and B. Mortensen, 1991, Indoor air mercury concentrations following application of interior latex paint, Arch *Environ. Contam. Toxicol. 21*, 62-64.

[140]. USEPA, 1992, *Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000*, EPA 530-R-92-013, USEPA, Office of Solid Waste and Emergency Response, April, 1992.

[141]. Beusterien, et al., 1991

[142]. Agocs, Mary, R. Etzel, R. Parrish, D. Paschal, P. Campagna, D. Cohen, E. Kilbourne, and J. Heese, 1990, Mercury exposure from interior latex paint, *New England Journal of Medicine, 323*, 1096-1101.

[143]. U.S. Department of Commerce, Bureau of Mines, Various years, *Minerals Yearbook*, U.S. Government Printing Office, Washington, D.C.

is that the half-life was approximately one year.[144] Other estimates are in approximate agreement with this value, although it appears from some data that the half-life could have been somewhat longer.[145] If a half-life of approximately 1.5 years and first-order exponential degradation are assumed, a relatively steady rate of supply of a material to a system would result in a quasi-steady state after 3 or 4 years. Regardless of the half-life, with a constant input a steady-state will evolve, where inputs to the system, in this case applications of mercury in paint, equal outputs, in this case mercury emissions. The mathematical expression of this relationship is $M_i = Mk$, where M_i represents the mass coming into the system, M represents the reservoir of mass in the system (in this case, painted surfaces) and k represents the rate of loss per time period. Mk thus represents the emission during the period.

With a steady input of 15,000 pounds per year, the yearly emission would have also been 15,000 pounds per year once steady-state was reached. With a half-life of 1.5 years, the steady-state reservoir would have been about 33,000 pounds. Once input ceased, which in the case considered here was approximately 1991, emissions would have tapered off.

Today, emissions from painted surfaces are likely to be less than 200 pounds per year, and should fall below 20 pounds per year within several more years. Related emissions resulting from discarded painted objects and paint containers, many of which probably made their way into waste streams and were incinerated, are also likely to be very low today, and declining. However, as recently as the early 1990s, emissions from this source may have been the largest single source of air emissions of mercury in the state. Some of these emissions were likely to indoor environments. That these emissions have largely disappeared today is evidence of the value of pollution prevention, which in this case took the form of elimination of mercury-containing biocides from paint.

Sectors Affected

None.

Receiving Media

Air.

Chemical Species

---

[144]. Minnesota Pollution Control Agency, 1998, *Options and Strategies for Reducing Mercury Releases, Source Reduction Feasibility and Reduction Strategies Committee Report*, Minnesota Pollution Control Agency, Policy and Planning Division, Majors Air Unit, 520 Lafayette Road, St. Paul, MN 55155, October 2, 1998.

[145]. Agnocs, M., et al., 1990.

The primary chemical species emitted from painted surfaces is believed to be elemental, although the parent compound itself, PMA or a related substance, may be emitted as well.

Reduction Options and Associated Costs and Impediments

Major reductions have already been achieved by cancellation of registration of mercury compounds used in paint and similar applications.

Research, Development, and Monitoring Options

Any new biocides added to paints should be thoroughly evaluated prior to introduction.

Outreach and Educational Options

No action necessary. This source is rapidly declining, and should approach zero in a few years. It is possible that some emissions may occur from old painted surfaces uncovered during renovations and re-painting operations. However, since the half-life of mercury in paint films is likely very low, and since most paint surfaces are porous to some degree, it is unlikely that significant amounts of mercury remain even in underlying paint layers.

Recommendations

No action necessary.

Crematoria

Identification and Description of Source

New Jersey's 19 crematoria disposed of 19,135 corpses in 1997.[146] This represents an increase over the 14,427 cremations of 1990 and the 18,385 cremations of 1995. This increase suggests that the consistent growth in number of cremations apparent nationally (50,000 cremations in 1958; 350,000 in 1989[147]) is mirrored in New Jersey. Dental fillings contain mercury, and when a corpse is cremated, this mercury is vaporized. Estimates vary on the number of fillings in a typical corpse, and the average quantity of mercury in those fillings. The reported range, assuming that amalgam is 50% mercury, is from 0.8 to 5.6 grams per corpse[148,149,150,151] with a mean of 2.9 grams mercury per cremated corpse.

Quantity and Estimated Uncertainty

There is some evidence that the actual emissions per cremation may be lower than the above data would suggest. One study indicated a release rate of 0.6 grams per corpse,[152] and another showed wide variations in amount emitted per corpse, with a mean of approximately 0.3 grams per corpse.[153] However, using a worst case approach, and assuming that the values noted above for quantity of amalgam per corpse are representative and that all mercury in amalgam is released upon cremation, multiplying 19,135 corpses cremated by 2.9 grams each equals about 120 pounds emitted from this source. The estimated uncertainty is high; at least 50%.

Sectors Affected

Funeral directors and associated businesses, especially the 19 crematories, would be affected by control measures. It is possible that efforts to reduce mercury emissions from crematoria will be opposed both by crematoria operators (because such measures could increase expenses and could conceivably discourage people from choosing cremation) and by dentists (who largely still favor

---

[146]. Dempsey, Pat, 1999, New Jersey State Funeral Directors Association, Manasquan, New Jersey, personal communication, June 17, 1999.

[147]. Leary, Warren, 1991, Even death a problem of pollution, Trenton Times, November 14, 1991.

[148]. Mills, A., 1990, Mercury and crematorium chimneys, *Nature 346*, 615.

[149]. Basu, M., and H. Wilson, 1991, Mercury risk from teeth, *Nature 349*, 109.

[150]. Skare, I., 1995, Mass balance and systemic uptake of mercury released from dental amalgam fillings, *Water, Air & Soil Poll., 80*, 59-67.

[151]. Kunzler, P., and M. Andree, More mercury from crematoria, *Nature 349*, 746-747.

[152] Obenauf, P. and S. Skavroneck, 1997, *Mercury Source Sector Assessment for the Greater Milwaukee Area*, prepared for the Pollution Prevention Partnership and Milwaukee Metropolitan Sewerage District, September, 1997.

[153] Midwest Research Institute, 1999, *Emission Test Evaluation of a Crematory at Woodlawn Cemetery in the Bronx, NY, Final Test Report, Vol. 1*, prepared for USEPA, Office of Air Quality Planning and Standard Emission Measurement Center, 4930 Old Page Rd., Research Triangle Park, NC 27709, Attn. Foston Curtis, September 30, 1999. Mean value of results presented is 0.16 g/hr., and report states that cremations take two hours.

use of mercury amalgams). A Funeral Directors Association representative reacted negatively to the suggestion that removal of fillings be required, stating that this would likely be offensive to relatives of the deceased and would interfere with the funeral process. Discussion of a variety of policy options to reduce crematoria emissions might encourage cooperation from both dentists and crematoria operators.

Receiving Medium

Air is the receiving medium.

Chemical Species

The mercury molecular species emitted are unknown. Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species such as $HgCl_2$, and species bound to particles are present.

Reduction, Research, Monitoring, Outreach/education Options, and Associated Costs and Impediments

In the long term, reduced use of mercury amalgams in dentistry will result in reduced emissions from crematoria, and will have the additional benefit of reducing mercury in dental wastewater, and reducing occupational exposures of dental workers. Alternatives to mercury amalgams are available and are becoming increasingly acceptable to dentists.

There has been a great deal of public attention on the potential (controversial) health risks of mercury amalgams. But there has been essentially no public education about the much more certain environmental impact of dental amalgams. While cremation may be an uncomfortable topic of discussion for some people, most people can nevertheless understand that if they have mercury amalgams in their teeth, that mercury is eventually going to end up in the environment. A sensitive, carefully thought out public education effort could encourage both dentists and patients to consider the environmental implications of the choice of mercury versus non-mercury dental amalgams.

In June 2000, the Dental Board of California ruled that dentists there must warn patients that silver (mercury) fillings will expose them to mercury, a metal on the state's list of hazardous substances. A similar type of warning could tell patients that use of mercury amalgams results in long-term emissions of mercury to the environment.

Some people who now have mercury amalgams might wish to take steps to ensure that their mercury fillings are not emitted into the atmosphere after they die. Living wills and organ donor programs could include options which would allow people to specify removal of mercury fillings prior to cremation.

Mercury emissions from crematoria could be controlled by the same technologies used for municipal waste incinerators and medical waste incinerators, such as carbon injection. The removal of mercury amalgams from corpses prior to cremation may be less expensive than installing pollution control equipment on crematoria.

Although this source represents a relatively small portion of the overall estimated air emissions in New Jersey, it has the potential to grow in magnitude. However, the expected increase in number of cremations may partially be offset by the reduced number of amalgams in Americans born after 1950 when fluoride use increased. Emissions from this source should be tracked and the estimated emissions quantity regularly updated.

Recommendations

- Encourage voluntary removal of amalgams from corpses, such as through living wills.
- Public education to encourage patients to consider the environmental implications of the choice of mercury versus non-mercury dental amalgams.
- Continue to track emissions inventory.
- Stack controls on crematoria.

Dental Office Waste

Identification and Description of Source

Mercury amalgam is used for dental fillings. Mercury-containing waste is generated from the creation of fillings and from the removal or replacement of fillings. The mercury in the fillings may be eventually released into the environment at the end of the patient's life; that amalgam pathway is discussed in the assessment of emissions from crematoria.

Quantity and Estimated Uncertainty

As of May 2001, there were 7,506 active dentists in New Jersey.[154] Review of data summarizing tests of wastewater leaving dental office buildings in six U.S. cities and one European city suggest that the mean discharge may be in the range of 0.1 g/dentist/day,[155] although the wide variation in methods and results of these studies suggest that this mean value should be considered very approximate.[156] This mean value is consistent with a Massachusetts study, which estimated that dental facilities discharge in wastewater from 0.06 g to 0.34 g mercury per facility per day.[157] Assuming that perhaps 10% of the dentists active in New Jersey do not routinely fill teeth, there are about 6800 dentists that might discharge in the range of 0.1 g mercury per day. This indicates that the contribution of dental amalgam to the wastewater flow from dental offices in New Jersey could be on the order of 450 lbs. per year, plus or minus at least 300 lbs./yr.

The chairside traps typically present in dental offices collect the larger particles of amalgam. These traps are reported to collect in the range of 60% to 70% of the total mercury waste.[158,159] Additional filter systems, such as vacuum filters or air/water separators present in many offices, will collect additional, smaller amalgam particles.[160] Assuming that about 30% goes down the

---

[154] NJ Department of Law & Public Safety (NJDLPS), 2001, from Melissa Roberts, NJDLPS, Division of Consumer Affairs, Bureau of Centralized Licensing, Trenton, NJ, May 14, 2001.

[155] Johnson, Bill, 1999; Mercury source identification update: dental offices and human waste, technical memorandum from Bill Johnson, EIP Associates, to Kelly Moran, Palo Alto Regional Water Quality Plant, Palo Alto, CA 94303. This memo reports the following estimated loads (grams/day/dentist) from dental offices; San Francisco, 0.035; Cleveland, 0.042; Seattle, 0.064; Boulder, 0.10; Boston, 0.043-0.27; Duluth, 0.1-0.3; Aarhus, Denmark, 0.25. The mean of these values is 0.121 g/dentist/day, with a 95% confidence interval of 0.044 to 0.198 g/dentist/day. Assuming 6800 NJ dentists use amalgam and operate 250 days per year, this translates to a mean of 451 lbs/yr, with a lower bound of 164 lbs./yr. and an upper bound of 737 lbs./yr., or approximately 450 ± 300 lbs./yr.

[156] Johnson, Bill, personal communication, June, 2001.

[157] Massachusetts Water Resources Authority (MWRA), 1997, Mercury in Dental Facilities, MWRA, Sewerage Division, Toxic Reduction and Control Department.

[158] Monroe County, NY, Department of Health. 1999. Use Best Management Practices for Amalgam Handling and Recycling. Available on the web as Appendix M in Promoting a Healthier Environment: Reducing Mercury Use in Health Care, http://www.epa.gov/glnpo/bnsdocs/merchealth/aboutmerhealth.html.

[159] EIP Associates, Mercury Amalgam Treatment Technologies for Dental Offices, technical memorandum prepared for Palo Alto Regional Water Quality Control Plant, July 10, 2000.

[160] Johnson, William and Teresa Pichay, 2001, Dentistry, Amalgam, and Pollution Prevention, CDA Journal, 29, 509-517.

drain, and that that quantity is about 450 lbs. per year, as estimated above, the amount collected in traps would be roughly 1050 pounds per year in New Jersey.[161] In New Jersey, this material is typically disposed in normal municipal waste or recycled. There is uncertainty associated with these numbers and the quantity could be higher. One study reported that, prior to any filtration or trapping, dentists discharge an average of 2 g mercury per day per dentist.[162] Other studies reported on the amount of mercury in dentists' wastewater passing through chairside traps. If these are the only filter used, the amount could be 0.8 grams per dentist per day;[163] and if chairside traps and vacuum filters both are used, the amount could be 0.4 grams per dentist per day.[164]

Quantities of mercury amalgam particles leaving dental offices in wastewater appear to vary widely; much of the variation may be due to factors within the plumbing system, such as low points, ridges, crevices, and traps that can collect small particles.[165] Compared to elemental and ionic forms of mercury, mercury bound within amalgam particles may be less available for conversion to ecologically harmful methylmercury.[166] However, it is possible that under certain conditions more available forms of mercury may be released from amalgam particles. Ultimately, most mercury in wastewater can be expected to reach wastewater treatment facilities or be discharged to septic systems. Quantities of mercury in wastewater, sludge, and emissions from solid waste incinerators and landfills are discussed in separate write-ups elsewhere in this document.

The amount of mercury that has been used in dentistry has been reported for many years.[167] These data can be apportioned to New Jersey based on population. Also, with the assumption that dental amalgam has a half-life of approximately 15 years in teeth, an estimated inventory in the New Jersey population can be developed. See Figures 1 and 2.

Sectors Affected

Dentists, their patients, and companies that supply materials to dentists and that provide services, including metals recycling, could be affected by efforts to reduce emissions from this sector. Insurance companies that do not currently pay the full costs of alternative restorations may also be affected.

---

[161] An estimated mass balance for dental-related mercury wastes in Canada suggested that about 4100 pounds of mercury was discarded per year from dentists' offices, and that about 1500 pounds of this went to the wastewater. stream. Since Canada's population is about four times New Jersey's, these quantities are in very close agreement with the New Jersey numbers.

[162] Drummond, J., Caila., M., et. al., 1995, Dental Waste Water: Quantification of Constituent Fractions, Academy of Dental Materials, Abstract P-22.

[163] EIP Associates, 2000, Mercury Amalgam Treatment Technologies for Dental Offices, technical memorandum prepared for Palo Alto Regional Water Quality Control Plant, July 10, 2000.

[164] Water Environment Federation, 1999, Controlling Dental Facility Discharges in Wastewater, Water Environment Federation.

[165] Johnson and Pichay, 2001.

[166] Johnson and Pichay, 2001.

[167] Minerals Yearbooks, various issues, U.S. Bureau of Mines and USGS, see http://minerals.usgs.gov/minerals/pubs/commodity/myb/

Receiving Media

Amalgam particles that are rinsed down drains or that escape poorly maintained chair-side traps and vacuum pump filters travel through the sewer system to the wastewater treatment plant. The material collected in traps and filters is typically disposed in ordinary municipal waste. Mercury amalgam may also be discarded on occasion with regulated medical waste, in which case the mercury could be incinerated in a medical waste incinerator. Extracted teeth, including any contained amalgam, are regularly discarded as medical waste.

Chemical Species

Dental amalgam is a mixture of elemental mercury with silver, tin, and copper. Mercury makes up about 40 to 50 percent of the amalgam compound.

Reduction Options and Associated Costs and Impediments

Source Reduction Options

Alternate, non-mercury fillings are available, and they are increasingly acceptable to dentists and patients. Many of the alternative fillings, which are composites that can be combinations of porcelain, zirconia, quartz, glass and plastic, are considered superior to mercury amalgam fillings for many applications. Not only are composite fillings tooth-colored rather than silver, they may also require smaller holes to be drilled to fill the cavity.

Nevertheless, adoption of non-mercury composite fillings has been slow. Some dentists still favor mercury amalgams because they are cheaper, easier to use, and they are confident that they are more durable. One dentist said that mercury fillings are still indicated for large fillings in back teeth where high durability is needed. Recently, however, many dentists appear to be moving away from mercury amalgam fillings and shifting to tooth-colored materials. One dentist supplied data that indicates that the percentage of restorations completed by his office that were mercury amalgam declined from 49% in mid-1997 to 20% in early 2000, and then to 12% by mid-2000. He stated that he has now become convinced that some non-mercury composite materials are superior to mercury amalgam, in part because they bond to the tooth and strengthen it. He also said he believes that use of amalgam by many dentists is only 10% of what it was a decade or two ago.[168] National mercury use data support the conclusion that less mercury is being used in dentistry. Figure 2 shows USGS data indicating that the quantity of mercury used in dentistry has declined by perhaps a factor of 3 since 1970.

However, some mercury use continues. It is reported that composite fillings can cost one-and-a-half to two times more than mercury amalgams, because the materials are more expensive and require more time to install. Further, it has been reported that most insurance companies do not cover the cost difference for non-mercury fillings in posterior teeth, or may not pay for a non-amalgam filling at all.

---

[168] Weiner, Robert, DMD, Personal communication.

Concerns over patient exposure to mercury amalgams may increase the pressure to phase out mercury amalgams. For example, the Dental Board of California, on June 30, 2000, advised dentists that they should discuss with their patients the different restorative materials, and warn patients that mercury fillings will expose them to mercury, a metal on the state's list of hazardous substances. In some countries, Sweden, Germany and Canada, dental societies have recommended against using mercury fillings in certain patients, such as pregnant women, people with kidney disease and children under age 6.

Concerns over mercury emissions from crematoria and medical waste incineration, due to mercury amalgams, may also increase the pressure to eliminate the use of mercury amalgam.

In order to remove obstacles to the reduced use of mercury amalgams, insurance companies should be required to cover both mercury amalgams and non-mercury composites. Additional measures to advance the phase-out of mercury amalgams should be considered. The Task Force recommends a goal of the phase-out of mercury-containing amalgam fillings within ten years and recommends that additional efforts be made to develop alternatives to mercury amalgam.

Control Options

The management of mercury-bearing dental office waste is essentially unregulated in New Jersey. But outside of New Jersey, a number of states and localities have taken measures to reduce mercury amalgam waste.[169,170] Massachusetts, Oregon, Minnesota, Michigan, Maine, Vermont, Seattle, Long Island, and San Francisco are among the states and localities that have developed dental amalgam waste management programs or regulations; as of June 2000, Pennsylvania is developing a program.[171,172] Minnesota's program is reported to have reduced the release of mercury amalgam in dental office wastewater by more than a factor of three.

As a first step, the basic guidelines for mercury amalgam waste management that have been adopted elsewhere in the country should be adopted in New Jersey as well. Manuals on best management practices for amalgam handling and recycling have been developed by a number of organizations. The recommendations from the Monroe County (New York) Department of Health are reprinted below.

Best Management Practices for Amalgam Handling and Recycling
(Monroe County, New York, Dept. of Health, 1999)

Amalgam Storage and Handling:

---

[169] Hughes, J., and Ingram, B. J., 1995, The Concern Over Mercury and Wastewater. *J. Michigan Dental Assoc.* April/May 1995.

[170] Western Lake Superior Sanitary District WLSSD, 1994. A Guide for Dentists: How to Manage Waste from Your Dental Practice, from Blueprint for Mercury Elimination, WLSSD, 2626 Courtland St., Duluth, MN, 218-722-0761.

[171] Oregon Dental Association 1998. The Environmentally Responsible Dental Office: The Oregon Dentist's Guide to Best Management Practices of Dental Waste.

[172] Massachusetts Water Resources Authority, 1998. Dentistry and the Environment.

Stock your amalgam materials in a good choice of capsule sizes, in order to better select the right amount of material for a particular restoration. This will minimize waste.

Dental scrap amalgam should be collected and stored in two designated, tightly closed, widemouth plastic containers. One container should be labeled CONTACT AMALGAM (amalgam that has been in the patient's mouth). The other should be labeled NONCONTACT AMALGAM.

Most recyclers prefer that contact amalgam be transported for recycling in a disinfectant. The liquid is visual evidence that the contact amalgam has been disinfected. Noncontact amalgam in a tightly sealed container can be stored and transported dry.

Amalgam Capsule Handling:

Collect and store the entire contents of broken or unusable capsules with your noncontact scrap amalgam. If empty dental amalgam capsules contain no visible amalgam materials, they may be placed in the trash.

If there is a spill of mercury from a capsule, contain it and clean it up immediately. Keep mercury clean-up materials on hand, and train a staff member in proper spill clean-up. Inexpensive mercury clean-up materials are available from science and safety equipment suppliers.

Amalgam Trap and Filter Handling:

When the fine particles of amalgam come in contact with cleaning agents and chemicals in the suction system and sewers, the mercury may be released. Large particles of amalgam can be prevented from entering the sewer system by the use of chair-side traps and vacuum pump filters. Material captured in the traps and filters can be sent to a recycler. Calculations based on data in scientific literature indicated that, when used properly, chair-side traps and vacuum pump filters can capture about 70% of the amalgam that enters the vacuum system.

- Never rinse scrap amalgam down the drain.
- Never place scrap amalgam in the medical waste red bag.
- Never place scrap amalgam in the trash.

Recommended techniques for collecting amalgam from the chair-side traps are as follows:

1. Change or clean chair-side amalgam traps often. The frequency may vary from daily to weekly depending on how often the chair is used for amalgam placement or removal and the effectiveness of the suction.
2. Flush the vacuum system with disinfecting line solution before changing the chair-side trap. The best method is to flush the line at the end of the day, and then change the trap the first thing the next morning.
3. Use universal precautions (gloves, glasses and mask) when handling the chair-side trap. Choose utility gloves intended for cleaning and handling wastes for this procedure.
4. Do not place gloves, plastic bags or paper towels into the recycling container. These add to the volume of the waste created and cause problems in the recycling equipment.
5. Remove all visible amalgam by tapping the contents into the container labeled CONTACT AMALGAM. Close the cover tightly. If the trap is visually clean, it can be put in the trash. These visually clean traps have been determined to be nonhazardous (shown by Toxicity Characteristic Leaching Procedure (TCLP) to be acceptable for landfilling). A heavily

contaminated trap should always be recycled. It should be placed in the contact amalgam container.

Vacuum pump filters are usually located upstream of the central vacuum pump. Recommended techniques for recycling the vacuum pump filters are as follows:

1. Replace or dispose of these filters regularly as recommended by the equipment manufacturer.
2. Use universal precautions.
3. Remove the filter and decant, over a tray, as much liquid as possible without losing visible amalgam.
4. Put the lid on the filter and place the filter in the box in which it was originally shipped. When the box is full, the filters should be recycled.

Plumbing Replacement and Repairs

After your office adopts its new amalgam management practices, it may be a good time to replace sink traps. Mercury from past practices often settles at low points such as sink traps and sump. The slow dissolution of the mercury in a sink trap or sump can release mercury into the wastewater for years after past disposal practices have been corrected. Whenever these plumbing parts are moved or cleaned, caution should be taken to avoid spilling the contents in case amalgam or mercury are present. Pour and brush out the sludge and handle it as you would handle contact amalgam. The plumbing parts can be put back in place or discarded in the trash.

Renovations:

If you have an older dental office, alert renovators to the possibility of mercury contamination in carpets, in floor cracks, behind moldings and other areas where bulk mercury may have been used, or where amalgam capsules may have been spilled. Call your county health department if you have questions about disposal of renovation debris.

Keep Informed on Separator Technologies:

Systems are available to treat wastewater contaminated with amalgam particles that are too fine to be caught in traps or filters. Most systems employ centrifugation or enhance sedimentation of particles. Some can also capture mercury that is in solution. Some of the new equipment can remove more than 99% of the mercury in the wastewater. It is used in some European countries, where removal rates of at least 95% are required. The systems are being evaluated in dental offices in the US. Equipment can be purchased or leased.

Recycle Bulk Elemental Mercury Stock:

In 1994 the American Dental Association recommended that dentists eliminate the use of bulk dental mercury by switching to precapsulated amalgam alloy in their practices. Measurement of the ratio of liquid mercury to amalgam powder is much more exact with the precapsulated technique. There is also less possibility of leakage during trituration. The use of precapsulated amalgam alloy eliminates mercury dispensers and containers as sources of mercury vapor, and eliminates the possibility of spillage of a large quantity of mercury.

Recycle Bulk Mercury. If there is a spill of a large amount of bulk mercury before it is eliminated from your office, call your county health department.

- Recycle any bulk mercury that may still be on hand in your office.

A list of locations to which amalgam waste can be sent for recycling in New Jersey needs to be developed. However, recycling is not an ultimate solution, since mercury may ultimately enter another source sector.

These basic guidelines do not suggest the installation of new equipment to remove mercury amalgam from dental wastewater. They primarily explain the procedures for mercury management and for recycling, rather than throwing away, the mercury amalgam that is collected by standard traps and filters.

Systems are available to treat wastewater contaminated with amalgam particles that are too fine to be caught in traps or filters.[173] Most systems employ centrifugation or enhance sedimentation of particles. Some can also capture mercury that is in solution. Some of the new equipment can remove more than 99% of the mercury in the wastewater. These systems are used in Germany and in Sweden, which require removal rates of at 95% and 90%, respectively, of the "chairside" mass loading. Such systems are reported to be required in dental offices in several US municipalities.

Research, Development, and Monitoring Options

The existing dental waste management programs only include the recycling of the large particles of amalgam trapped in standard dental office filters, and recycling of any leftover amalgam. The standard dental office filters do not trap small particles or mercury in solution. The potential use of more effective systems, such as those already required in Sweden, Germany, and elsewhere should be considered.

Reasons for the current cost differential between mercury-containing amalgam and alternate materials (e.g., materials, labor, etc.) should be determined.

Outreach and Educational Options

Dental associations in the U.S., unlike associations in some other countries, have been resistant to phasing out mercury. Outreach to dentists and dental societies to clarify the reasons for switching to alternatives is important. Public education will encourage consumers to select non-mercury restorations.

New Jersey dentists and the New Jersey Dental Association are largely unaware of the need to collect and recycle mercury amalgam wastes. DEP should work with the New Jersey Dental Association and local and regional mercury recyclers to adopt guidelines for management of mercury waste that are at least as stringent as those that have already been implemented elsewhere in the United States.

---

[173] Fan, P. L. et al., 1997, Environmental Issues in Dentistry - Mercury. *International Dental Journal*, 47:105-109.

Recommendations

- Adopt in New Jersey effective guidelines for mercury amalgam waste management that have been adopted elsewhere in the country.
- Reduce the use of mercury-containing amalgam through a public education/awareness program encouraging selection of alternatives.
- Phase out the use of mercury-containing amalgam for dental fillings.
- Require insurance companies to cover the cost of non-mercury restorations.
- In New Jersey, follow the California model of requiring dentists to explain the properties of mercury and the relative costs and benefits of mercury vs. non-mercury restorations.

Figure 1
Mercury in amalgam; estimated inventory in NJ population

from U.S. Bureau of Mines and USGS data, apportioned to NJ
assuming 15-year half-life for mercury in tooth fillings

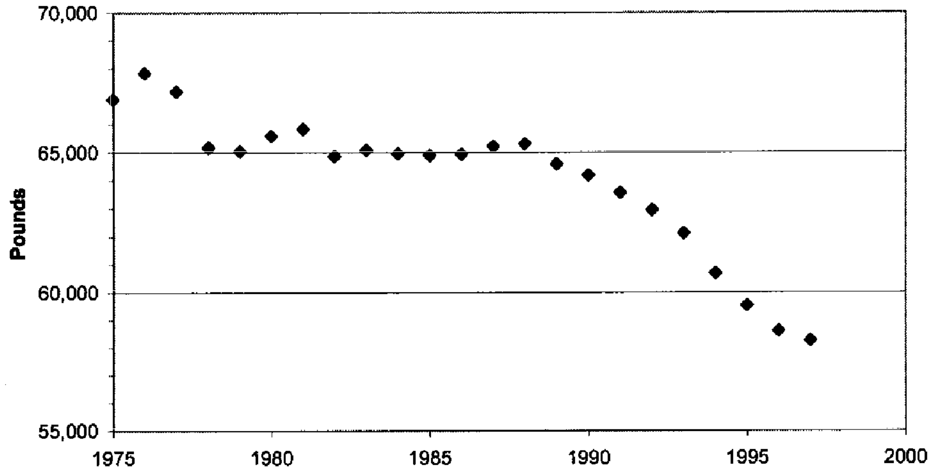
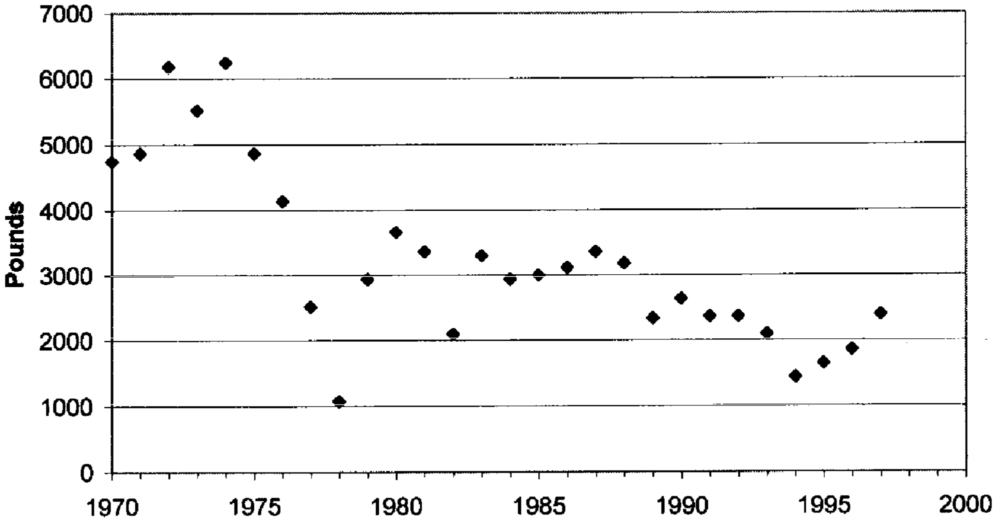


Figure 2
Mercury used in dentistry, NJ

from U.S. Bureau of Mines and USGS data, apportioned to NJ



Laboratories

Identification and Description of Source

Mercury is used in laboratories in instruments, reagents, preservatives, and catalysts. Some of this mercury could be released in laboratory wastewater or solid waste streams. Such quantities will be included within other write-ups discussing wastewater and solid waste management facilities, including landfills and incinerators. Some mercury is emitted directly to the atmosphere.

Quantity and Estimated Uncertainty

In 1994, in the U.S., an estimated 1.1 tons of mercury were emitted into the atmosphere from general laboratory use.[174] Apportioning this quantity to New Jersey, based on population, suggests that approximately 70 pounds of mercury per year are released. The relatively high density of research facilities in New Jersey suggests that this quantity should be adjusted upward by perhaps 25%. An emission of approximately 90 pounds per year from this source is assumed.[175]

Sectors Affected

Laboratories, which are primarily associated with the industrial and commercial sectors, including health care facilities and educational institutions, could be affected by measures to reduce emissions from this source.

Receiving Media

Emissions to the air, expected to be primarily through lab vents, are included in this source. Possible laboratory emissions to water and solid waste are included in the total estimates for these sources, discussed in other write-ups in this document.

Chemical Species

Species emitted are expected to be primarily inorganic mercury species, including elemental mercury. Pharmaceutical companies use and may release various organic species such as Thimerosol.

Reduction Options and Associated Costs and Impediments

Carbon adsorption filters could be used on affected lab hoods as necessary, with added costs.

---

[174] USEPA, 1997, *Mercury Study Report to Congress, Volume II; An Inventory of Anthropogenic Mercury Emissions in the United States*, EPA-452/R-97-004, December, 1997.

[175] 1.1 ton/250 million US population x 8 million New Jersey population x 2000 lb./ton x 1.25 ≈100 lb. mercury emission from general lab use per year in New Jersey.

Research, Development, and Monitoring Options

Better data on actual emissions from this source are desirable.

Outreach and Educational Options

Outreach and education efforts offer the opportunity of reducing use and estimated releases. Such efforts could be targeted to scientific and research organizations.

Recommendations

- Require carbon adsorption filters in laboratory hoods.
- Acquire better data on quantities of release.
- Reach out to scientific and research organizations to encourage the use of practices that reduce emissions.
- Laboratories should document purchases and spills of mercury and mercury compounds.
- Alternatives to mercury and mercury compounds should be encouraged.

Medical Waste Incineration

Identification and Description of Source

Medical waste, which includes infectious (red bag) and non-infectious waste from medical and veterinary offices, clinics, and hospitals, is incinerated at 11 facilities in New Jersey, including hospitals and research facilities.

Quantity and Estimated Uncertainty

Stack tests carried out pursuant to NJDEP permits indicate that the total emissions from these facilities are very low, in the range of 2 pounds per year.

Sectors Affected

The facilities that incinerate the waste would be affected by efforts targeting this sector.

Receiving Media

The emissions are to the air.

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particles are present.

Reduction Options and Associated Costs and Impediments

Pollution prevention measures, including source reduction, re-use, recycling, and separation prior to incineration could all be effective. These practices are currently being employed to a large degree, and this is a major reason emissions from this sector are so low in New Jersey. Mercury sources in medical waste include batteries, fluorescent lamps, thermometers, plastic pigments, antiseptics, diuretics, infectious waste bag pigments and CAT scan paper.

New Jersey should adopt the New England Governors/Eastern Canadian Premiers[176] recommended emission limit for medical waste incinerators. All New Jersey medical waste incinerators already have achieved this level with pollution prevention measures. Adopting a limit will prevent backsliding and help provide an example to other jurisdictions.

Many previous sources have been closed due to more stringent air emission standards. The federal government has set a goal of reducing air emissions of mercury from this source by 90% by the year 2005.

---

[176] New England Governors/Eastern Canadian Premiers Mercury Action Plan, 1998, http://www.tiac.net/users/negc/1998mercuryplan.html, June 1998.

Research, Development, and Monitoring Options
Outreach and Educational Options/Recommendations

None recommended due to the low quantity of the source in New Jersey.

Medical Waste, Not Incinerated

Identification and Description of Source

Mercury-containing items from this source category result from the disposal of waste that is generated by the healthcare industry. Mercury can be found in both biomedical and normal solid waste streams produced by medical facilities as described below.

A study was commissioned by the Florida Department of Environmental Protection to evaluate the use of mercury in Florida's medical facilities[203]. This study concluded that the medical industry in Florida uses mercury in the following products or devices:

Thermometers
Sphygmomanometers
Medical tubes
Switches
Barometers
Manometers
Gauges
Mercury-containing lamps
Batteries
Plastics (mercury in plastic pigments)
Laboratory products and reagents
Veterinary products
Vaccines and pharmaceuticals
Dental amalgam

A listing of more specific sources of mercury can be found in Appendix B of the Florida report. For example, under the general category of laboratories, Appendix B lists six mercuric chloride-based fixatives, thirteen mercury-containing reagents and seven stains that contain mercury compounds. The Task Force expects that the medical facilities in New Jersey utilize similar products in their operations.

In general, wastes produced by medical facilities take four forms: biomedical waste, hazardous waste, solid waste and low-level radioactive waste. Low-level radioactive waste disposal is not an issue associated with mercury in New Jersey. Potential mercury releases associated with solid waste and hazardous waste are discussed elsewhere in this document.
Biomedical waste is referred to as Regulated Medical Waste (RMW) in New Jersey and is regulated by the New Jersey Solid Waste Regulations, Subchapter 3A. These regulations define RMW as:

"...any solid waste, generated in the diagnosis, treatment (for example, provision of medical services), or immunization of human beings or animals, in research pertaining thereto, or in the

---

[203] Florida Center of Solid and Hazardous Waste Management, Mercury in Florida's Medical Facilities: Issues and Alternatives. Report #S-97-15, December 1997.

production or testing of biologicals, that is not excluded or exempted under (b) below, and that is listed or meets any waste characteristic classification criteria described in the following table:

TABLE
REGULATED MEDICAL WASTE

	Waste Class	Description
1.	Cultures and Stocks	Cultures and stocks of infectious agents and associated biologicals, including: cultures from medical and pathological laboratories; cultures and stocks of infectious agents from research and industrial laboratories; wastes from the production of biologicals; discarded live and attenuated vaccines; and culture dishes and devices used to transfer, inoculate, and mix cultures.
2.	Pathological Wastes	Human pathological wastes, including tissues, organs, and body parts and body fluids that are removed during surgery or autopsy, or other medical procedures, and specimens of body fluids and their containers.
3.	Human Blood and Blood Products	Liquid waste human blood; blood; items saturated and/or dripping with human blood; or items that were saturated and /or dripping with human blood that are now caked with dried human blood; including serum, plasma, and other blood components, and their containers, which were used or intended for use in either patient case, testing and laboratory analysis or the development of pharmaceuticals. Intravenous bags, soft plastic pipettes and plastic blood vials are also included in this category.
4.	Sharps	Sharps that were used in animal or human patient care of treatment or in medical research, or industrial laboratories, including sharp, or potentially sharp if broken, items such as, but not limited to, hypodermic needles, all syringes to which a needle can be attached (with or without the attached needle) and their components, including those from manufacturing research, manufacturing and marketing, pasteur pipettes, scalpel blades, blood vials, carpules, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are other types of broken or unbroken glassware that were in contact with infectious agents, such as used slides and cover slips.
5.	Animal Waste	Contaminated animal carcasses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biologicals, or testing of pharmaceuticals.
6.	Isolation Wastes	Biological waste and discarded materials contaminated with blood, excretion, exudates, or secretions from humans who are isolated to protect others from certain highly communicable diseases, or isolated animals known to be infected with highly communicable diseases.
7.	Unused Sharps	The following unused, discarded sharps, that were intended to be used: hypodermic needles, suture needles, syringes, and scalpel blades."

Exclusions from the preceding definition can be found in the New Jersey Administrative Code at N.J.A.C. 7:26-3A-6.

Due to the nature of the operations conducted in medical facilities, mixing of the different types of wastes can occur. Items that are broadly contaminated with regulated body fluids (human or animal) must be segregated and handled as medical waste in New Jersey if the items are not cleaned for reuse. More importantly, those mercury-containing items that are disposed of are combined with mercury-free waste as "red bag" waste. Because of the potential infectious nature of red bag waste, the opportunity for source separation and/or recycling of these mercury-containing items is lost once the wastes are mixed.

The disposal method for waste produced by medical facilities is dictated by the type of waste produced. Solid waste can be discarded with regular wastes via the municipal waste disposal system. Regulated medical waste disposed of within New Jersey must be sent to a registered intermediate handler/destination facility along with a mandatory New Jersey medical waste tracking form. Regulated medical waste may be transported only by transporters registered with the State of New Jersey. Medical waste disposed of out-of-state is required to be shipped with a medical waste tracking form as well. Generators are required to verify that out-of-state medical waste disposal facilities are authorized to accept such wastes by the receiving state. Regulated medical waste is disposed of and/or treated by various methods. Medical waste is considered "destroyed" in New Jersey when it is no longer generally recognizable as medical waste because all components of the waste have been ruined, torn apart, or mutilated to produce unrecognizable and unusable pieces smaller than three quarters of an inch (sharps must be less than one half inch). Medical waste "treatment" is defined as a change in the biological character or composition of regulated medical waste to reduce or eliminate its potential for causing diseases through such methods, techniques or processes as incineration, steam sterilization, chemical disinfection, irradiation, thermal inactivation or any other effective method approved by the State Department of Health.

Some of the various methods used to treat medical waste are:

- Incineration - is the thermal destruction of waste for the purpose of treatment, destruction and volume reduction of the regulated medical waste. Incinerators must be permitted by the NJDEP for this purpose.

- Sewer disposal - is the direct disposal of liquid regulated medical waste into the municipal sewer system for the purpose of treatment and destruction of liquid waste.

- Steam sterilization - is the thermal treatment of regulated medical waste using steam, sometimes generated within the waste through the use of microwave or radio frequency radiation. Steam sterilization alone does not normally destroy the waste.

- Chemical treatment - is the use of a chemical such as sodium hypochlorite to treat the regulated medical waste. Chemical treatment alone does not normally destroy the waste.

- Irradiation - is the use of ionizing radiation to destroy infectious organisms in the regulated medical waste. Irradiation alone does not normally destroy the waste.

- Thermal inactivation - is the use of high temperatures to destroy infectious organisms in the regulated medical waste. Thermal deactivation alone does not normally destroy the waste.

- Disposal of RMW in a sanitary landfill - is the direct disposal of regulated medical waste in sanitary landfills. In New Jersey, only treated RMW is authorized for disposal at specially-permitted landfills for RMW.

On June 24, 1998, the American Hospital Association (AHA) and the U.S. Environmental Protection Agency (EPA) signed a "Memorandum of Understanding" (MOU) that calls for reducing hospital waste by 50% by the year 2010.[177] This MOU also sets the goal of eliminating

---

[177] American Hospital Association. U.S. Environmental Protection Agency and AHA Enter Partnership to Reduce Hospital Waste. Press Release, June 24, 1998.

mercury from the hospital waste stream by the year 2005. Under this MOU, the AHA and EPA have agreed to the following:

1. Undertake collection of baseline data on hospitals' pollution prevention efforts;
2. Monitor hospitals' success in meeting goals of reducing waste;
3. Sponsor educational seminars about waste management and mercury reduction;
4. Participate in an Environmental Leadership Council, a group comprised of hospital leaders, EPA officials, environmental groups, and others that will provide recommendations to the AHA about educational and outreach activities to hospitals, health systems and health care workers to help reach these waste reduction goals; and
5. Develop Internet-based model waste minimization plans for hospitals targeted at specific chemicals.

If the goals of this program are realized, mercury pollution from many health care facilities will be minimized by the year 2005. The AHA presently has a membership of 5,000 hospitals, health care systems, networks and other care providers.

Quantity and Estimated Uncertainty

In July 1993, the previous New Jersey Mercury Task Force estimated that regulated medical waste comprised approximately 30% of the total hospital waste.[178] The total quantity of regulated medical waste reported, based on 1991 figures, was approximately 17,000 tons. The total amount of regulated medical waste generated in New Jersey in 1999 is approximately 70,770 tons according to the Bureau of Resource Recovery and Technical Programs.[179] Of this quantity, 34,550 tons were managed by incineration or landfilling for final disposal. The large increase in the amount of regulated medical waste generated in the State between 1991 and 1999 is not necessarily due to increased waste production. Rather, a substantial proportion of the apparent increase may be the result of better reporting and record keeping related to medical waste within the State.

---

[178] New Jersey Department of Environmental Protection and Energy. Final Report on Municipal Solid Waste Incineration. Volume III, Technical And Regulatory Issues. July 1993.

[179] 1999 Annual Regulated Medical Waste Generator and Transporter Reports, data provided by the NJDEP Bureau of Resource Recovery and Technical Programs. Data is reported from generators and transporters and has not been verified.

Analysis of New Jersey-generated Regulated Medical Waste Disposition (tons)
(source: data from the RMW Annual Generator Reports for 1999)

Total RMW generated in NJ 1999	70,770
Portion managed via sewer disposal (liquids)(est.)	36,220
Portion incinerated or landfilled	34,550
Portion processed on-site in NJ.	
Incineration	831
Alternative technology	6,523
Total	7,354

It should be noted that mercury contained in sewer-disposed liquids has been accounted for in the sludge write-up contained in this report. Likewise, mercury released by incineration and that disposed of in landfills is accounted for in specific write-ups elsewhere in this report.

The quantity (i.e., average concentration) of mercury in New Jersey's medical waste has not been quantified. However, Volland has calculated an average mercury concentration of 15 ppm in medical waste incinerated by medical waste incinerators monitored during performance tests conducted by the California Air Resources Board from 1987 to 1989.[180] Using a maximum mercury concentration of 15 ppm for the regulated medical waste generated in New Jersey, approximately 1036 pounds of mercury is disposed of annually. The Task Force believes that the mercury content of regulated medical waste generated in New Jersey is significantly less than 15 ppm for several reasons. First, the data used by Volland were collected more than 10 years ago. Since that time, the medical industry, and hospitals in particular, have become more aware of the presence of mercury in its waste streams. Source separation programs such as battery and fluorescent lamp collection and recycling programs implemented at hospitals remove several of the high-mercury contributors from the medical industry waste stream. Second, many alternatives to mercury-containing products have been developed in the last 10 years. Use of these mercury-free products results in decreased mercury in the waste produced. Considering these waste reduction measures, the Task Force estimates the present average mercury concentration of regulated medical waste is closer to 5 ppm than to 15 ppm. It should be emphasized that the 5 ppm average is an estimate only. The Task Force has no data to support this estimate. Calculations based on this 5 ppm assumption indicate that approximately pounds of mercury are disposed of as a component of the regulated medical waste streams generated in New Jersey.

Sectors Affected

The facilities that process medical waste using the methods described herein would be affected by efforts targeting this sector.

---

[180] Volland, C. Emission of Volatile Heavy Metals from Medical Waste Incinerators. *Proceedings of the 85th Annual Meeting & Exhibition of the Air & Waste Management Association,* Kansas City, Missouri, 1992.

Receiving Media

The distribution of mercury to the environment as a result of the disposal of regulated medical waste is dependent upon the disposal method. Medical waste that is incinerated, or otherwise heat treated, will release mercury and mercury compounds primarily to the atmosphere, although some mercury will be scrubbed out of the gas stream by air pollution control devices and sent to landfills. Medical waste that is sent directly to landfills for disposal can release mercury to soil and/or groundwater. Finally, sewer disposal of medical waste that contains mercury can release mercury to water or to the sludge produced during wastewater treatment. The RMW disposed of in municipal wastewater (sewerage) systems is comprised largely of blood and blood products, biological production wastes and funeral home discharges. This liquid RMW likely contains little added mercury from anthropogenic sources.

Mercury releases from New Jersey medical waste incinerators, municipal solid waste incinerators, landfills, in wastewater, and in wastewater treatment sludge are accounted for in the inventories discussed in other sections of this document.

The approximately 7,354 tons incinerated and treated using alternative technologies could provide a mercury source for atmospheric or surface water deposition. Some of the amount processed using alternative technologies would be incinerated at municipal waste incinerators or landfilled in state, while some would be disposed of out of state.

Chemical Species

Mercury in medical devices such as thermometers, manometers and thermostats exists as elemental mercury. Dental amalgam also contains mercury in the elemental form. Mercury in laboratory reagents is in the form of compounds, both organic and inorganic. Examples include mercury iodide, mercury chloride, mercury oxide, mercury nitrate and mercury sulfate. Batteries used in pacemakers, hearing aids and equipment such as defibrillators contain mercuric oxide. Plastic pigments may contain cadmium-mercury compounds and it has been reported that the red pigment and black print used in red bags also contain mercury.[181] As previously mentioned, medical waste incinerators are suspected of emitting mercury as mercuric chloride due to the reaction of mercury and chlorine components of plastics and packaging that make up this waste stream.

Reduction Options and Associated Costs and Impediments

Source Reduction

The primary opportunity for reduction of mercury from medical facilities is for the facilities to purchase and use mercury-free products. Alternatives exist for many of the products, instruments and components identified for this source category. However, it is up to the

---

[181] Florida Center of Solid and Hazardous Waste Management, Mercury in Florida's Medical Facilities: Issues and Alternatives. Report #S-97-15, December 1997.

individual facility to voluntarily institute the necessary controls to screen purchased items. Smaller facilities are at a disadvantage and will be challenged by the effort required to implement such a program. Indeed, these facilities may be unaware that the need even exists. In view of this, successful reduction efforts for smaller facilities should consist of education combined with guidance. All medical facilities, regardless of size, should be encouraged to conduct a mercury inventory that serves as a starting point for reduction efforts.

Additional activities that will result in a reduction of mercury pollution are:

Segregation of waste streams

An organized approach to waste management will keep hazardous wastes separate from non-hazardous wastes, infectious wastes segregated from other wastes and recyclable wastes separate from non-recyclables. This approach, if implemented properly, will prevent mercury-containing items from being deposited into waste containers that might be sent to disposal facilities not equipped to handle mercury-bearing wastes. Known mercury-containing wastes, such as batteries and fluorescent lamps, should be collected and sent for recycling, where feasible.

1. Medical facilities should procure mercury-containing chemicals in quantities that will be used completely before the shelf life expires. Expired reagents should be disposed of at a proper disposal facility. Out-of-date reagents should not be disposed of by pouring them into a sink or floor drain.

2. Medical facilities should assure mercury spill kits or specialized vacuum devices are available to confine and collect spilled mercury and mercury-containing materials. The materials collected should be sent to a mercury recycler whenever possible. Special, separate containers should be made available for mercury spill clean-up and collection wastes.

3. Implement best management practices.

Control options

After researching the alternative treatment methods that may be used in New Jersey, the Task Force determined that mercury releases from some of the processes may be possible. For example, microwave treatment of regulated medical waste may heat the waste to temperatures that would drive off mercury. It is not clear at this time whether mercury releases from alternative treatment facilities is an area of concern. It is also unclear whether any alternative treatment facilities operating in New Jersey are equipped with air pollution control devices that collect mercury.

Research, Development, and Monitoring Options

Research mercury content of regulated medical waste to more accurately determine the potential release of mercury by the various disposal options. In addition, review the operational aspects of alternative treatment facilities and assess the potential for mercury releases from these processes.

Outreach and Educational Options

Efforts directed at educating New Jersey businesses about minimizing potential health risks through mismanaging mercury-containing waste will result in an increased awareness of mercury pollution issues. Outreach efforts should be concentrated on the medium and small medical waste generators that may not currently recognize the potential for mercury pollution that may result from their activities.

Recommendations

- Use mercury-free products in hospital and veterinary and medical offices.
- Segregate mercury-containing waste streams.
- Procure mercury-containing chemicals in quantities that will be used completely before the shelf life expires.
- Manage mercury spills appropriately.
- Research mercury content of regulated medical waste.
- Review the operational aspects of alternative treatment facilities and assess the potential for mercury releases from these processes.

Dredged Materials Management

Identification and Description of Source

Dredging in the State of New Jersey directly affects the viability and sustainability of New Jersey's ports and waterways.[182] New Jersey does not consider dredged material to be a solid waste. Dredged materials are, by definition, sediments that are removed from river and bay bottoms in the process of constructing or maintaining maritime infrastructure such as docks, bridges, berthing areas and navigation channels. These sediments are not, by definition, contaminated but can be contaminated with any number of natural and man-made pollutants that have been improperly or imprudently disposed in or near the water. In the Port of NY and NJ, much of the sediment is contaminated. However, elsewhere in the State, dredged materials are relatively clean. As discussed in more detail below, it is estimated that greater than 17,000 pounds of mercury in dredged materials are moved annually by maintenance dredging in the NY/NJ harbor alone.

New Jersey's coastal zone is comprised of a number of natural, cultural and socio-economic environs. Dredging and the management of dredged material vary throughout the coastal zone in response to the specific environmental conditions. To effectively manage dredging and dredged material, it is useful to break the coastal zone into three regions. Region 1 extends from Sandy Hook westward and northward, encompassing the Raritan Bayshore, Newark Bay, New York Harbor and industrialized waterways of the northeastern part of the State. Region 2 encompasses the Atlantic seaboard inclusive of tidal rivers and back bay areas from Sandy Hook south to Cape May. Region 3 encompasses the Delaware estuary from Trenton south to Cape May. These Regions are recognized in the Department's dredging technical manual.[183]

The characteristics of the sediment to be dredged vary among these regions. The methods of dredging and management strategies also vary. In Region 1 most dredging is accomplished by mechanical means (clamshell bucket). The majority of material dredged from this region is either used as remediation material at the Historic Area Remediation Site (HARS) or is beneficially used in remediating contaminated upland sites. The HARS is the site of historical dredged material disposal in the ocean located about 6 miles off of Sandy Hook. The current management strategy for the HARS is to cap previously contaminated dredged material with

---

[182] Port and recreational uses of the State's tidal waters add significantly to New Jersey's economy. The Port of New York and New Jersey is the largest container port on the east coast, generating an estimated 166,500 direct and indirect jobs and an estimated 20 billion dollars in regional economic activity (PANJ/NJ, 1999). Along the back bays of the State's Atlantic seaboard, recreational boating and commercial fishing in 1989 contributed in excess of 877 million dollars to the State's economy (NJDEP, 1990). Lastly, the Delaware River supporting the fourth busiest ports on the East Coast contributes an estimated 3.5 billion dollars and 30,000 jobs to the regional economy. In addition to these fiduciary benefits are the less tangible benefits of reduced truck traffic and associated air emissions and infrastructure maintenance. The continuation of these benefits is only possible through dredging to maintain navigability.

[183] NJDEP, 1997, *The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters*, NJDEP, Office of Dredging and Sediment Technology, Trenton, NJ.

three feet of clean dredged material, thereby isolating contaminants from the marine environment. The U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers share responsibility for determining whether material meets the criteria for use as remediation material. Dredged material which is unsuitable for use at the HARS is currently being stabilized and placed on contaminated upland sites as part of an overall remediation or closure strategy for those sites under DEP oversight.

Region 2 exhibits the greatest variability in the management of dredged material. Material in Region 2 may be removed by either mechanical or hydraulic (dredged material slurried with site water and pumped to a disposal location) means. Historically, much of the material dredged from Region 2 had been placed in confined disposal facilities (CDFs) constructed by placing berms on coastal wetlands, and then pumping the dredged material into the enclosure. Recently, more innovative management techniques have been required in Region 2, due in large part to the development of former CDFs, changes in the wetlands regulatory program that make siting new CDFs difficult, and the limited capacity in the remaining CDFs. These emerging management strategies range from use as daily landfill cover, beach nourishment, or general fill as appropriate.

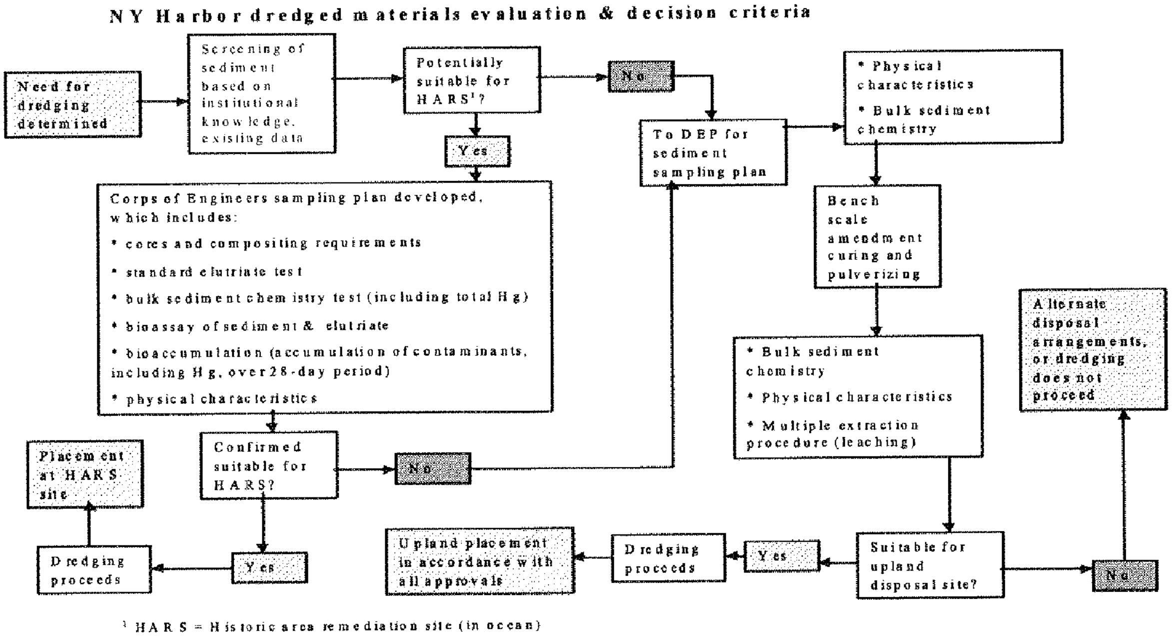
In Region 3 most material is dredged by the Army Corps of Engineers (ACE) by hydraulic means with the material being pumped into large CDFs situated along the Delaware River. However, sandy material is routinely used for beach nourishment or is placed in the Delaware Bay. Privately dredged material is usually dredged by mechanical means and bottom dumped into a rehandling basin, located at the foot of the Commodore Barry Bridge, prior to being pumped up to nearby CDF.

Prior to the issuance of a permit to dredge, the dredged material must be sampled and tested. There are few exceptions for very small scale projects (mostly in Region 2) and projects consisting of 90 percent or greater sand, where analytical testing may not be required. Figures 1 and 2 depict the evaluation and decision criteria that apply to the dredging process and to dredged materials in both the New York/New Jersey Harbor and the Delaware Estuary. Analytical testing required in all three regions includes bulk sediment chemistry (including total mercury), although the analytes may be reduced in some regions based on probability of occurrence (e.g. dioxins and furans). Other analytical tests may also be required, and are determined based on project specific information including the method of dredging (e.g. modified elutriate test for hydraulic dredging) and the proposed end use of the dredged material (e.g. sequential batch leaching test for upland confined disposal, and bioassays for in water disposal).

Excluding dredging for beach replacement, historically an average of 4-6 million cubic yards of sediments have been removed each year from the New York/New Jersey Harbor alone. The material is removed by the U.S Army Corps of Engineers, the Port Authority of New York and New Jersey and by other private entities that require dredging of their berthing areas. However, the amount of material dredged from the State's tidal waterways varies from year to year. In addition, because most contamination of concern in dredged materials results from anthropogenic sources, it is useful to separate new work dredging, (virgin material consisting mostly of rock, sand and clays) from maintenance dredging, (accumulated material consisting mostly of silts). The projected average annual volume of maintenance dredged material for the next 10 years is about 2.6 million cubic yards.[184]

Based on ocean disposal testing criteria,[185] the majority of this material (75%) removed from the New York/New Jersey Harbor is not suitable for placement at the Historic Area Remediation Site (HARS) off the New Jersey coast.[186] Material not suitable for the HARS is placed on upland sites for brownfield remediation and for construction purposes, such as sub-bases for parking lots, golf courses and other areas where geotechnical fill is required. In order to de-water, stabilize and solidify the dredged material for these purposes, it is almost always mixed with Portland cement, lime or fly ash/kiln dust prior to its land placement. Sediments are also removed from the Delaware Estuary. These materials are typically hydraulically pumped to upland disposal sites in southern New Jersey. Figures 1 and 2 depict the evaluation and decision criteria that apply to the dredging process and to dredged materials in both the New York/New Jersey Harbor and the Delaware Estuary.

Figure 1. NY/NJ Harbor dredged materials evaluation & decision criteria



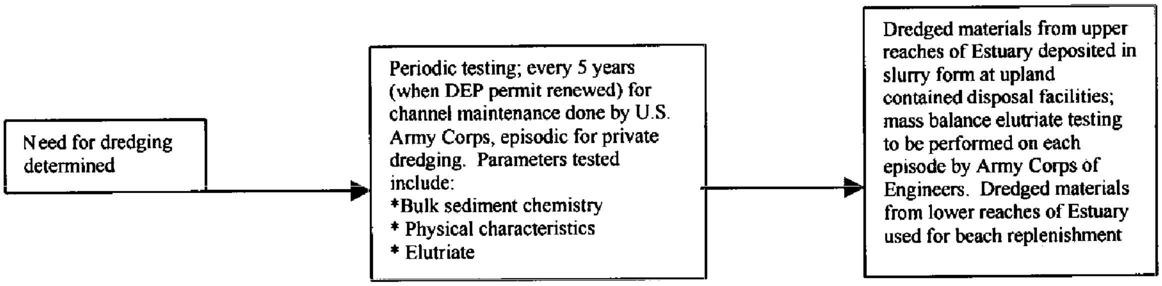
---

[184] NJDEP, 2000, Office of Dredging and Sediment Technology, Trenton.

[185] These criteria were established by the Environmental Protection Agency Region 2 Office and the New York District of the Corps of Engineers for testing material to be disposed of at the Historic Area Remediation Site (HARS) off the New Jersey coast.

[186] Almost all of the dredged material placed at the HARS contains a measurable amount of mercury; however, it is generally less than 3 ppm total mercury.

Figure 2. Delaware Estuary dredged materials evaluation & decision criteria



Quantity and Estimated Uncertainty

Sediment sampling has shown that typical dredged material contains mercury at widely varying concentrations depending on where it came from and at what depth dredging took place. Based on sediment sampling conducted by the National Oceanic and Atmospheric Administration (NOAA), the average concentration of mercury in New York Harbor sediment is estimated to be 2.88 parts per million (PPM).[187] An independent review of sediment sampling results from 16 project reaches in the New York/New Jersey Harbor region, comprising a total of 120 analytical samples, found a mean mercury concentration in sediments of 2.09 ppm.[188] This research found the lowest average concentration (0.388 ppm) in Kill Van Kull, and the highest average concentration (6.24 ppm) in Arthur Kill. Sediment in the Delaware Estuary has been found to be considerably lower in mercury content; the average sediment mercury concentration from 81 stations was found to be 0.14 ppm.[189]

Multiplying the tonnage of dredged material by the average concentration of mercury yields a total in excess of 17,000 lbs. of mercury being moved annually by maintenance dredging in the New York Harbor alone.

There are a number of possible routes where mercury in dredged materials could reach the environment. Figure 3 depicts these routes for a typical NY/NJ Harbor dredging process with upland disposal.

---

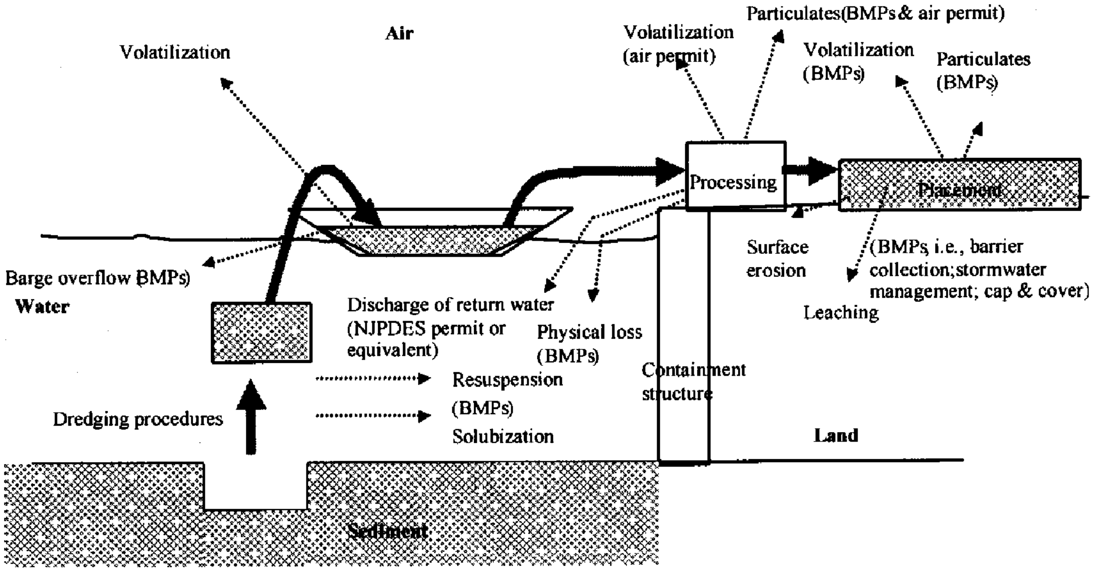
[187] NOAA, 1994 REMAP sediment sampling and characterization effort.

[188] NJDEP, 2000, Office of Dredging and Sediment Technology, Site Remediation Program, PO Box 028, Trenton, NJ.

[189] National Oceanic and Atmospheric Administration (NOAA), 1998, Draft data for the Mid-Atlantic Integrated Assessment (MAIA).

One such route is the dredging process itself. The emission of mercury to air should be trivial during the dredging process. But there is a potential effect on the water body being dredged during the dredging activity when some sediment particles may fall off from the chunk of dredged material. These resuspended particles may contain mercury. Based on recent work by Feng et al. (1999) in the Hudson River estuary[190], the residence time of suspended particles in the water column ranged from <1 to 10 days. However, it has been found that in most areas of the Hudson estuary the residence time of particles is <1 to 2 days. So, these particles normally quickly sink to the bottom. However, Feng et al. (1999) also reported that during a tidal cycle in the Hudson River estuary, the suspended particles can be transported as far as 15 kilometers from the dredging site.

Figure 3. Mercury in Dredged Materials: Possible Transfer Routes and Associated Controls (in parentheses)



There remains some question as to whether the dredging activities could increase the availability of mercury to fish and other aquatic organisms. In one study involving a model simulating the uptake of mercury in fish resulting from upstream dredging, a 30% increase in mercury concentration in pike was predicted.[191]

---

[190] Feng, H. and J. K. Cochran and D. J. Hirschberg. 1999. ^{234}Th and ^{7}Be as tracers for the transport and dynamics of suspended particles in a partially mixed estuary. Geochimica et Cosmochimica Acta, *63*, 2487-2505.

[191] Schultz, Titta, P. Korhonen, and M. Virtanen, 1995, A mercury model used for assessment of dredging impacts, *Water, Air and Soil Pollution 80*, 1171-1180.

Another potential source of mercury release to the environment could be the processing step, where materials such as Portland cement are mixed with the dredged materials to stabilize and solidify it. It currently is not known how much mercury is released to the air during this mixing. Because the process is exothermic (heat releasing), mercury could be volatilized at that time; but how much this would increase the annual release rate is unknown. Pursuant to NJDEP air permits, a mass-balance comparison of mercury concentrations in unprocessed and processed materials will be performed at an upland disposal operation expected to be underway by the fall of 2000. Results of this process should indicate whether a large discrepancy exists, which would signal a potentially significant air emission.

Another potential release source is the placement site itself. In order to estimate the potential for air emissions from the mercury contained in dredged material at placement sites, two estimates were calculated. Both assumed that six million cubic yards of dredged material is generated statewide each year and that 75% of it is placed on the land.[192] Both also assumed the solid content of dredged material is 40% (it generally ranges from 30% to 40%) and that the volatilization rates under wind velocity of 5 – 35 km/hr are respectively 0.0047-0.0055%, based on a 7-day cycle of replenishment of new materials on the placement site and 0.0066-0.0082% based on a 3-day cycle. Based on these rates, if mercury concentration in the dredged materials is assumed to average 2.88 ppm, a volatilization rate of 0.23-0.28 kg/y (0.51-0.62 lbs./yr.) is predicted with a 7-day cycle. If the cycle is 3 days, the predicted rate is 0.33-0.41 kg/y (0.73-0.90 lbs./yr.).[193] There is a high degree of uncertainty in both of these estimates, but they should represent an approximation of mercury volatilization if one ignores the stabilization/solidification process.

Mercury that is not emitted to the air can remain in the dredged material regardless of whether or not the dredged material is stabilized. However, within the dredged material, mercury can diffuse from high concentration areas to low concentration areas through pore spaces due to molecular diffusion processes. The rate of this diffusion depends upon the moisture content of the material. Therefore, during heavy rain events, rainwater may penetrate though the dredged material and get into the ground. If this is the case, a certain amount of mercury may be transported into the ground. The amount of mercury getting into the ground depends on many factors such as the porosity of ground soils, concentrations of mercury in the dredged material and the amount of rainwater, as well as the mercury partitioning between the solid and liquid phase. Relatively speaking, however, the concentration of mercury in the water entering the ground would be quite a bit lower than that in the dredged material.[194] Further, in the New York

---

[192] These "worst case" estimates are based on conversations with members of the Dredge Team in Region 2 of the U.S. Environment Protection Agency. Since the vast majority of material dredged in New Jersey is represented by the 4-6 million cubic yards removed each year from New York/New Jersey Harbor, a statewide maximum estimate of 6 million cubic yards was used to calculate mercury releases to the air. Similarly, since 50%-75% of this dredged material is disposed of on the land, the higher figure was used for calculation purposes.

[193] H. Feng, Ph.D., 2000, Model calculations based on realistic assumptions, H. Feng, Department of Earth and Environmental Studies, Montclair State University, Upper Montclair, NJ 07043.

[194] H. Feng, Montclair State Univ.

Harbor area where mercury concentrations in dredged material are the highest, dredged material placement sites are designed with engineering controls including groundwater containment and/or leachate collection.

For most of the potential mercury release routes, best management practices (BMPs) are in place to minimize releases and other problems. These BMPs are summarized below:

Standard Dredging Site Best Management Practices for Work in the New York Harbor

- Dredging to be accomplished with a closed "environmental" clamshell bucket dredge (minimizes the loss of water and sediments from the bucket during lift).
- Dredged to be operated so as to maximize the "bite" of the clamshell (fewer trips through the water column).
- Dredge bucket lift speed shall not exceed two feet per second (minimizes loss of material during lift).
- Dredged material to be deliberately placed in the scow (minimizes loss of material during transfer of material and splashing of material out of the scow).
- No barge overflow (prevents the discharge of sediment-laden water from the scow back to the water).
- All scow are to be permanently sealed or of solid hull construction (eliminates the potential loss of material through the split-hull scow (bottom) doors).
- No hosing or rinsing of the gunwales or sides of the scows during dredging (reduces the resuspension of material lost from the scows during transfer).
- Dredging only on flood (or ebb) tide depending on contaminated sediment patterns in the waterway being dredged.
- Silt curtains to be deployed where maximum current velocity does not exceed 1 knot (controls resuspended sediment around the operating dredge).
- Dredging to be accomplished to a uniform depth so as not to create anoxic holes in the channel bottom.
- Standard Best Management Practices and Regulatory Approval Conditions Applied to the Processing Facility.
- Use of spill plate between the scow and the bulkhead during unloading of dredged material (keeps material spilled out of the bucket during unloading from entering the water).
- Routine sweeping (frequency to be specified) of the unloading area and reintroduction of all spilled material into the product stream (reduces the potential for sediment to reenter the waterway).
- Stormwater management requiring full capture, containment and treatment of the 1-year storm prior to discharge of stormwater from the unloading/processing area (minimizes the loss of sediment into the water associated with stormwater runoff).
- Discharges of return water or decant water regulated by either a NJPDES permit or a Water Quality Certificate. Permits routinely require minimum retention or settling times, monitoring requirements for constituents of concern and total suspended solids with action levels prior to discharge. A NJPDES Permit allows for the discharge of return water from a different waterway at the processing site. WQC is issued for those facilities

discharging into the same waterbody from where the dredged material originated. A WQC includes the same settling times, monitoring conditions and/or action levels as a NJPDES DSW permit.

- Air discharges regulated under Air Pollution Control Permit. Permit conditions now include fugitive emission control, intake limits on constituents of concern and preliminary bulk sediment testing for total Mercury at both the intake of the processing plant as well as on the processed (adjusted for residence time in the pug mill) material. This testing is done to detect any potential volatilization of Mercury during processing. If a loss is detected, more sophisticated monitoring and controls may be required.

Best Management Practices and Controls Employed at the Placement Site

The placement sites are subject to DEP oversight, either Site Remediation Program or Bureau of Landfill Engineering. The sites must have an approved remedial action work plan or landfill closure design. These approved plans typically include the following:

- Groundwater containment, collection and / or treatment to be installed prior to accepting dredged material (these systems prevent potential release of contaminants to groundwater).
- Requirements for stormwater management during closure including capture and treatment of stormwater from the site (prevents erosion of material from the site).
- Clean fill cap or other cover (prevents long term exposure of dredged material to the air, reducing or eliminating long-term volatilization and particulate emissions).

In addition, the following best management practices are employed at the site:

- Processed dredged material is placed on the site in one-foot lifts (for compaction purposes so that the desired density for future site construction and/or development is achieved).
- Processed dredged material is placed while still wet after processing to help keep fugitive dust to a minimum. Even after placement, the material is kept wet by water trucks which are in continuous operation to control fugitive dust.
- Processed dredged material cannot be placed during periods of heavy rainfall.
- The slopes of the placement site must be such that the processed dredged material does not slough away from the area where it is placed.
- Vehicle traffic over and in the area of freshly placed processed dredged material must be minimized so that the material has a chance to dry and thus stabilize in the area where it is placed. This reduces the chance that the material can become airborne.

Receiving Media

Potential receiving media are discussed above, and depicted in Figure 3.

Chemical Species

Chemical species are unknown. Mercury is believed to exist in sediments primarily as the virtually insoluble compound, HgS. However some exists in other forms, including methylated species, and may be bound within organic matrices in biota or within detritus. Species of mercury that could be emitted from processing or at other locations are not known.

Reduction Options and Associated Costs and Impediments

Follow the above best management practices to minimize volume and loss and to maximize containment at sites with minimal environmental impact.

Research, Development, and Monitoring Options

The DEP, with input from the Office of New Jersey Maritime Resources, the U.S. Army Corps of Engineers, and the U.S. EPA, should complete a review of literature regarding potential increases in bioavailability from solubization and resuspension into the water column during the dredging process and from processing and land placement. Any such increases expected should be compared with potential bioavailability from sediments if left in place. The outcome of the review should be the ascertainment of whether a need for additional research or monitoring is warranted.

If necessary, based on literature review or additional data, the DEP, with input from the organizations listed above, should formulate recommendations for upgrades to dredging procedures and equipment to the best reasonably available methods to minimize any solubization or resuspension that may occur.

The DEP should perform a mass-balance comparison of mercury concentrations in unprocessed and processed materials. Results of this process should indicate whether a large discrepancy exists, which would signal a potentially significant air emission.

Measure, either at laboratory or field scale, releases to air and water from stabilization processing site(s) and upland placement site(s). If such releases appear significant, review and improve procedures to ensure that significant volatilization or other releases do not occur.

Outreach and Educational Options

Continue dialogue with policy makers, educators, industry and the public to increase understanding of the issue and the need for basing decisions on sound science.

Recommendations

- Research releases during handling and stabilization.
- Clarify potential releases from the dredging itself.
- Modify federal legislation that currently prevents the use of the latest dredging technology because the equipment in not manufactured in the U.S.
- Continue to manage and monitor upland placement sites.

Hazardous Waste Incineration

Identification and Description of Source

A hazardous waste incinerator is a unit that thermally treats hazardous wastes for reducing the volume and toxicity of the waste. The facilities generally have the capability of treating wastes in one or more of the following states: solids, liquids, sludges and gases. A typical incinerator consists of three major components: a waste feed unit (rotary kiln, liquid injection unit, etc.), an afterburner or secondary combustion chamber and an air pollution control system. Wastes in solid or sludge form are fed to the rotary kiln portion of the incinerator. Liquid and gaseous wastes may be fed to either the rotary kiln or directly to the afterburner, depending on the configuration of the equipment. Gases produced by the incineration process pass from the feed unit to the afterburner where any remaining organic materials are combusted, and then through the air pollution control system. The air pollution control system removes or neutralizes particulate, heavy metals, acid gases and sulfur dioxide from the gas stream before it is discharged through a stack to the atmosphere. Residuals generated by the incineration process are ash from the solids incinerated and sludge produced from treatment of the water used in the air pollution control system. Both of these residual materials are collected and treated as a hazardous waste and shipped to a hazardous waste landfill.

The wastes that can be treated by incineration, including those that contain mercury, are limited by federal regulations. These regulations may be found at 40 CFR Part 268, commonly referred to as the Land Disposal Restrictions. During the initial waste approval process, wastes that contain high levels of mercury are not acceptable for incineration. In addition, the EPA policy of impermissible dilution, which prohibits combustion of certain inorganic metal-bearing wastes, serves to direct mercury-contaminated inorganic wastes to reclaiming and/or recycling facilities and away from hazardous waste incinerators.

Quantity and Estimated Uncertainty

Prior to May 2001, there were five operating hazardous waste incinerators in New Jersey. Four of these were non-commercial. In a press release issued January 31, 2001, the only commercial hazardous waste incinerator operating in New Jersey announced that it would cease operation as of May 8, 2001, and that it would stop receiving wastes on April 30, 2001. One of the remaining four non-commercial incinerators is believed to emit less than 0.5 lbs./yr. of mercury. The three remaining units are believed to emit less than 12 lb./yr. mercury.[195] Up until May 8, 2001, the quantity of mercury released as of the year 2000, from the one commercial incinerator has been estimated to be approximately 50 pounds per year. Therefore, the total emissions of mercury from the 3 non-commercial and the one former commercial incinerator for the year 2000 are estimated to be 62 lbs. per year. This estimate may vary by an estimated 10 to15 % depending on the mercury concentrations and volume of waste incinerated.

---

[195] USEPA Region II data files, 2001.

Work by the first New Jersey mercury task force indicates that releases of mercury from municipal solid waste combustion ash are low.[196] To the extent that the chemistry of the ash and its disposal environment are similar for hazardous waste ash, mercury emissions should likewise be low.

Sectors Affected

Efforts to limit emissions from this sector would affect the incinerating facilities themselves, as well as generators of hazardous waste that ship their wastes to be incinerated.

Receiving Media

The chief receiving medium is believed to be air due to the volatility of mercury and mercury compounds. Mercury may also be transferred off-site to hazardous waste landfills as components of ash and sludge, but the amounts are assumed to be minimal due to the inherent volatility and method of treatment.

Chemical Species

The chemical species of mercury released from combustion units, including hazardous waste incinerators, is difficult to quantify precisely. It is generally assumed that elemental mercury, when present, is volatized during combustion and released as elemental mercury. The species of mercury released from waste materials containing mercury bound in both organic and inorganic matrices is less certain, and probably consists of a combination of elemental, oxidized and mercury salt forms.

Reduction Options and Associated Costs and Impediments

There are three major potential control strategies for mercury at hazardous waste incineration facilities. The most important strategy is the continued segregation of high-mercury compounds from the waste that is to be incinerated. Wastes reported to contain high levels of mercury are refused for treatment and routed to reclaiming facilities or other approved treatment and disposal operations.

Source Reduction

Mercury is not used directly in the incineration process, and source reduction opportunities are not available through a modification of the incinerator facility or process. The primary emphasis for mercury source reduction from this industry lies with the generators of hazardous waste. Mercury incorporated into products during the manufacturing processes is present in off-specification batches, spill clean-up wastes and product returns that are disposed via incineration. Thus, elimination or reduction of mercury used in manufacturing processes will result in a

---

[196] New Jersey Department of Environmental Protection & Energy, 1993, *Task Force on Mercury Emissions Standard Setting, Final Report on Municipal Solid Waste Incineration, Volume III, Technical and Regulatory Issues*, Chapter 11, Environmental Effects of Mercury Control on the Solid Waste Stream, pp. 11.1 to 11.10, NJDEP, Trenton, NJ, July, 1993.

decline in the mercury content of wastes produced and a commensurate decrease in the emissions from the incineration of these wastes.

Control Options

A second option for mercury reduction is to transfer mercury-bearing wastes to mercury recovery facilities instead of treating the wastes by incineration. Inorganic mercury-containing wastes at almost any concentration can be treated, but the economics of recovery of low concentrations of mercury are usually cause to select another treatment option. In addition, mercury reclaimers generally cannot recover mercury from organic compounds and this limitation is another reason these wastes are sent to incinerators.

The third option for reducing mercury emissions from hazardous waste incinerators is the use of add-on control devices to remove mercury from the gas stream exiting the unit. Presently, several systems that use carbon injection or carbon fluidized bed technology appear to be the most effective for mercury removal.

Under the new Air/RCRA MACT rule promulgated by EPA, allowable mercury emissions from hazardous waste incinerators are to be decreased to 130 micrograms per dry standard cubic meter. At this time it is unclear as to whether this lower emissions level will require the incinerator to install new controls to meet this limit.

Research, Development, and Monitoring Options

Little is known about the speciation of mercury emitted from hazardous waste incinerators. Research directed at confirming the type and quantity of mercurial compounds produced would allow for a more thorough understanding of how mercury from combustion sources enters and cycles through the environment. In turn, the risks posed by emissions from combustion could be quantified more accurately.

Outreach and Educational Options

Outreach and educational efforts aimed at general mercury reduction strategies will indirectly affect the emissions from the commercial incinerator receiving these wastes. As stated earlier, a reduction in the use of mercury as a raw material will have a direct impact on the quantity of mercury presented to incinerators for treatment. Efforts directed at discouraging non-essential mercury use will be useful in an overall mercury pollution prevention program.

Recommendations

- Eliminate or reduce mercury used in manufacturing processes.
- Continue to keep wastes having high mercury content out of the incineration stream.
- Transfer mercury-bearing wastes to mercury recovery facilities.
- Add mercury control devices to hazardous waste incinerators.
- Confirm the type and quantity of mercurial compounds produced by incineration.

- Encourage the general reduction of use of mercury as a raw material.

Hazardous Waste Sites

Identification and Description of Source

Since the 1970s, New Jersey and the New Jersey Department of Environmental Protection have been at the forefront of identifying and characterizing hazardous waste sites. New Jersey has more sites on the National Priorities List (about 10% of the total) than any other state. To date, a total of thirty-eight mercury-contaminated sites have been reported. The sites are listed based on exceedence of ground water quality criteria or soil guidance criteria.[197,198] Fifty percent of the sites had contamination in both soils and ground water, while the remainder had only ground water contamination. Of the sites reporting both soil and ground water contamination, 90.5 % of the sites were located in northern and central New Jersey, reflecting the greater degree of industrialization in the northern part of the state. A total of fifteen sites had only ground water impacted by mercury contamination, and these sites were all located in the southern part of the state. Of these 15 sites all but one involved contaminated potable drinking water wellfields. Free product mercury has been found at the Atlantic City Air National Guard Facility, former Du Pont Chemical Pompton Lakes explosives works, Ewing Navel Air Warfare Center, and the Albee Development site in Hoboken.

Soil contamination by mercury is generally not characteristic of an entire site. Generally soil contamination is limited within a site to certain areas of concern commonly referred to as hot spots. However, the Du Pont Chemical Pompton Lakes facility, Troy Chemical Site (Newark), Ventron/Velsicol (Berry's Creek area in Bergen County), and LCP Chemical Inc. Site (Linden), show more of a site-wide pattern of soil contamination by mercury. Soil contamination (where detected) ranged from 0.68 ppm to 34,700 ppm. Five sites with soil contamination had soil levels of mercury in excess of 1,000 ppm.

Ground water contamination at sites can be transported horizontally and thus can be more of a site-wide problem. Ground water levels (where detected) ranged from below the drinking water maximum contaminant level (MCL) of 2 ppb to 2,250 ppb. This latter high figure was observed at Cosan Chemical Company near the locus of Berry's Creek. The specific groundwater values for the south Jersey wellfield sites were not provided at the time of the case manager survey. Surface water sediments ranged from 0.35 ppm to a high of 60,000 ppm, and included both fresh and salt water systems.

---

[197] In New Jersey, the Ground Water Quality Standard for mercury is 2μg/L (2ppb). The residential Soil Guidance Criteria for mercury is 14 mg/kg (14 ppm) and the Industrial soil guidance criteria for mercury is 270 mg/kg or 270 ppm. These human-health based values are based on total mercury and do not consider speciation.

[198] Any sites which show exceedence of the criteria numbers should be listed within the inventory of mercury contaminated sites. The Site Remediation Program (SRP) has no contaminant specific data base, so that the information collected herein was acquired by a general request for case mangers with mercury contaminated sites to respond with general information relevant to mercury contamination at their sites. Thus we cannot be sure this list is comprehensive. In some instances the sites also reported surface water and sediment contamination.

Air emissions of mercury have been measured at the Ventron/Velsicol site, with levels as high as 60.6 ng/m^3 . In recent years gentrification in Hoboken (Hudson County) has included two attempted conversions of former fluorescent bulb factories to multiple family condominium units. In both instances occult globules of residual mercury led to mercury levels in ambient air in excess of health standards.

Remediation at these sites has been limited since many are still being investigated. Capping has been planned for some sites, while vacuum collection has been the remediation technique at sites with free elemental mercury. At the Merck Facility thermal treatment with carbon absorption has been used to remove mercury from contaminated soils.

Quantity and Estimated Uncertainty

No estimates have been made of the quantities of mercury that may be leaving the identified sites and entering the ambient environment. Any such quantities are believed to be low. For purposes of this report, a yearly emission to the ambient environment of 10 pounds or less is assumed.

Sectors Affected

Individual sites could be affected by measures to reduce mercury releases to the environment.

Receiving Media

Releases could enter the air, adjacent water bodies, or surrounding soils and sediments.

Chemical Species

Chemical species are likely to be highly varied, and include elemental mercury and a wide variety of mercury compounds.

Reduction Options and Associated Costs and Impediments

The listed sites are included in the NJDEP's overall plans for hazardous site clean-ups; options and costs are determined and managed on a case-specific basis.

Research, Development, Monitoring, and Outreach and Educational Options

Although no data exist to indicate that releases of mercury from hazardous sites to the ambient environment occur in significant quantities, further data would be useful. Air monitoring at selected sites could be particularly informative. In general, a more holistic view of sites should be considered, with attention given to possible transport of mercury contamination beyond the site boundaries.

Recommendations

- Monitor air emissions at selected sites to ascertain occurrence of significant releases to the environment.

Landfill Gas

Identification and Description of Source

There are an estimated 475 million cubic yards of solid waste deposited in the 578 known and suspected landfills in New Jersey.[199] With the assumption that the mercury content of the deposited solid waste is approximately 2.5 ppm[200], and that a cubic yard of compacted solid waste weighs 1000 pounds, the waste in place in New Jersey contains approximately 1.2 million pounds of mercury. Clearly, if even a modest percentage of this mercury is emitted, the quantity emitted would be significant. As solid waste decays, it releases gas. Landfill gas is approximately 50% CO_2 and 50% CH_4. Other compounds are present, including trace quantities of gaseous mercury species. Over half of the landfill gas generated by New Jersey landfills is burned, either in flares or for energy production.[201] Burning landfill gas might change the chemical species of any emitted mercury, but would not reduce the total quantity of emitted mercury.

Quantity and Estimated Uncertainty

A formula has been developed by the USEPA to estimate the emission of gas from landfills. This formula, used in conjunction with specific dates of operation and rates of waste deposition for the known New Jersey landfills,[202] suggests that approximately 1.7 billion cubic meters of gas per year are produced from New Jersey landfills.[203] Stack test data exist on the concentrations of mercury in landfill gas from several landfills in the New Jersey region.[204] These data indicate an

---

[199] Information received from the NJDEP, Division of Solid and Hazardous Waste, January 1999, indicates the total 1997 volume of waste in place in 98 NJ landfills of greater than 100,000 cubic yards in volume was approximately 415 million cubic yards. An additional 60 million cubic yards is estimated by NJDEP/DSR&T to be present in an additional 300 landfills smaller than 100,000 cubic yards.

[200] NJDEP, 1993, *Task Force on Mercury Emissions Standard Setting, Vol. III*, Chapter 1, NJDEP, Trenton, NJ 08625.

[201] Based on information received from NJDEP Division of Solid and Hazardous Waste, 7/99, estimated landfill gas emissions, and estimated collection and combustion efficiency.

[202]. Information received from NJDEP, Division of Solid and Hazardous Waste, January 1999.

[203] Formula used is first-order decay formula from: USEPA, 1996, Turning a Liability into an Asset, EPA 430-B-96-0004. This formula is CH_4 $ft^3/yr = Lo \times R \times (e^{-kc} - e^{-kt})$. The "c" is time in years since closure of the landfill; "t" is time in years since opening. Input values of k = 0.04/yr and Lo = 1.765 cf/lb. were used, along with site specific data and estimates. This formula generates a volume, in cubic feet per year, of release of methane, which then is multiplied by 2 to estimate the total gaseous emission in cubic feet, and converted to cubic meters.

[204] The average mercury concentration in a series of stack tests performed at three landfills in New Jersey, the Ocean County LF, Fort Dix LF, and Edgeboro LF, and the Fresh Kills LF in Staten Island, NY, NY, is in the range of 5 to 10 $\mu g/M^3$. The reported gas Hg concentrations (in separate sampling events or locations within each landfill) were, for Fresh Kills, 7.32, 17.5, 31.28, and 9.78 $\mu g/M^3$; for Edgeboro, 0.99, 1.06, and 1.34 $\mu g/M^3$; for Ocean Co., 2.7 $\mu g/M^3$, and for Ft. Dix, 0.04, 0.16, and 0.3 pounds per year. New Jersey LF data are NJDEP stack test data,

average concentration in the range of 7.5 micrograms (µg) mercury per cubic meter of landfill gas. Multiplying this concentration by the total estimated volume of landfill gas suggests that approximately 30 pounds per year of mercury are emitted from New Jersey landfills.

Another calculation generates a comparable quantity. With this latter method, the mercury emission factor of 2.9×10^{-4} ppm Hg in landfill gas is used.[205] This factor suggests that, in New Jersey, there are approximately 10 pounds of mercury emitted from landfills.[206]

Sectors Affected

Landfills would be affected by any additional control or management efforts.

Receiving Media

The receiving medium is air. Some mercury is also released from landfills in the form of leachate. This release is discussed in another section.

Chemical Species

No information is available on the species of mercury emitted; all concentrations have been expressed as total mercury. If a significant portion of the species emitted are methylated, even the relatively low quantities from this source could be important. A recent study found 50 nanograms of dimethyl mercury per cubic meter in landfill gas.[207] This quantity, if typical of all landfill gas, would translate into what appears to be a relatively insignificant emission of approximately 85 grams (about 0.2 pounds) per year in New Jersey.

Reduction Options and Associated Costs and Impediments, and Research, Development, and Monitoring Options

Mercury going to landfills will be reduced by the removal of mercury from products. Further research should be conducted to determine whether a significant portion of the mercury released from this source is in the form of methyl mercury. The low concentration of mercury in landfill gas in relation to other sources argues that no efforts to control this source are necessary at this time.

---

with additional calculations. Fresh Kills data contained in letter from Elizabeth Capdevielle, GSF, Inc., 3321 Bee Caves Rd., Austin TX, to NJDEP, Jan. 3, 1997.

[205] USEPA, 1997, Mercury Study Report to Congress, Volume II; An Inventory of Anthropogenic Mercury Emissions in the United States, EPA-452/R-97-004, December, 1997, page 3-8.

[206] Multiplying 1.7 billion M^3 by 2.9×10^{-10} (2.9×10^{-4} ppm) indicates that about 0.5 M^3 of mercury would be released. Assuming that 1000 ft^3 of methane weighs 42.3 pounds, 1000 ft^3 (28 M^3) of Hg^o would weigh 200.59/16 times as much (the ratio of the molecular weights). Therefore, 0.5 M^3 would weigh about 10 pounds.

[207] Lindberg, S.E., et al., 2001, Methylated mercury species in municipal waste landfill gas sampled in Florida, USA, Atmospheric Environment, 35, 4011.

Recommendations

- Reduce mercury in products.
- Analyze landfill gases using state-of-the-art protocols and laboratories to determine mercury species and quantities.

Landfill Leachate

Identification and Description of Source

Leachate is liquid discharged from a landfill. Liquids are produced within the landfill through the decay of wastes, and also result from the percolation of precipitation through the landfill surface. Leachate is generated at solid waste landfills including those that are operating and those no longer receiving waste. The newer operating landfills have impermeable liners and leachate collection systems that are designed to prevent the discharge of leachate to the surrounding environment. Many of the older closed (inactive) landfills, however, lack these environmental controls and are, therefore, the most likely sources of mercury discharges. Groundwater monitoring systems are in place at the operating sites as well as at closed facilities that ceased operations after January 1, 1982. Mercury results from groundwater monitoring wells are reported at least once a year under the NJPDES Discharge to Groundwater testing requirements. Approximately 20% of the closed landfills, however, do not monitor for mercury. Landfill leachate itself is not generally tested on a regular basis at the older closed sites.

Quantity and Estimated Uncertainty

Mercury is currently found in a limited number of monitoring wells at less than 10% of the closed landfills (numbering less than 10 sites) that are reporting data. Recorded amounts are generally in the low parts per billion range. These sites are primarily located in the southern portion of the state.[208] A recent report[209] indicates that about 60% of monitoring wells showed mercury below detection or less than 2 μg/l. About 18% of the monitoring wells had levels > 10 μg/l. About 12.5% of the landfills had one or monitoring wells with a mercury concentration > 20 μg/l. Leachate concentrations from several New Jersey landfills were also reviewed. These included the Sussex County Landfill, the Salem County Utilities Authority Landfill, and the Edgeboro Landfill.[210] These data were either below the detection limit (2 μg/l and 1 μg/l), or estimated to be 0.5 μg/l . Using a value of 5μg/l as conservatively representative of leachate mercury concentration, and assuming that there are about 5000 acres of landfill surface in the state with no leachate collection and that about one half meter of rain infiltrates these surfaces each year and becomes leachate, about 110 pounds of mercury is emitted per year in the form of landfill leachate.[211]

Uncertainty arises in the positive identification of the landfill as the source of the mercury found in some leachate samples and in estimating the overall quantities of the pollutant being discharged to the environment. These uncertainties result from the limited availability of leachate data and the lack of hydrogeologic information at many of the closed landfill sites.

---

[208] Based on information received from NJDEP Division of Solid and Hazardous Waste.

[209] Barringer, J., C. MacLeod, and R. Gallagher, 1995, *Distribution of Mercury in Ground Water, Soils, and Sediments of the Kirkwood-Cohansey Aquifer System in the New Jersey Coastal Plain, and Hypotheses as to Potential Sources of the Mercury*, USGS, Mountain View Office Park, West Trenton, NJ 08628.

[210] NJDEP Central File, 1995 NJPDES Permit Discharge Monitoring Reports, NJDEP, Trenton, NJ 08625.

[211] 5000 acres is about 2000 hectares, or 2 × 107 m2. An infiltration of 0.5 m/yr of rain translates to 1 × 107 m3 of leachate, which is 1 × 1013g. With a mercury concentration of 5 μg/l, 5 × 104 g, or 110 pounds mercury exists in this quantity of leachate.

Sectors Affected

Landfills would be affected by any additional control or management efforts. Many landfills in New Jersey are closed, and are under the jurisdiction of the USEPA or the NJDEP.

Receiving Medium

The main receiving medium is groundwater generally located in the first shallow aquifer underlying the landfill. Any movement of leachate to deeper aquifers or discharge to nearby surface water is dependent upon the hydrogeology of the particular landfill site.

Chemical Species

Mercury results are reported as "total" in the NJPDES groundwater monitoring reports for the landfills. Multiple species may, therefore, be present. The species of mercury in leachate are unknown. Virtually all of the mercury included in aqueous media, including leachate, is likely to be soluble mercury. Water-soluble environmental mercury species include the divalent mercuric ion, Hg^{++}, mercuric chloride ($HgCl_2$), the anionic complexes HgX_3^-, HgX_4^{-2}, with $X = OH^-$, Cl^-, or Br^-, and mixed halide complexes such as $HgCl_2Br^-$,[212] although some of the total could also be methyl mercury, CH_3Hg^+.

Reduction Options and Associated Costs and Impediments

Capping of closed landfills with impermeable material and the collection of leachate where feasible would serve to minimize discharges of leachate to the surrounding environment. [Acceptance of mercury containing waste in active landfills should continue to be discouraged.]

The installation of an impermeable cap and collection of leachate are options available to the landfill owner under the DSM closure regulations. Difficulties are encountered in obtaining dedicated funding for the closure and post-closure activities at closed landfills, especially those owned by municipalities. Since these landfills are no longer operating, they do not generate revenues. Nevertheless, the municipalities must budget for closure costs and provide dedicated escrow monies for post-closure maintenance and monitoring of the landfill sites over a 30-year post closure period in accordance with the closure regulations. As a result, shortfalls in funding are common.

Research, Development, and Monitoring Options

Groundwater wells at solid waste landfills should continue to be monitored under the NJPDES-DGW program to determine long-term trends for detectable levels of mercury.

---

[212] DeNoble, James P., 1999, Critical Review: *Atmospheric Methylmercury: Sources, Sinks, and Inferences for its De Novo Generation*, DRAFT Masters Thesis, Rutgers University, October, 1999.

Outreach and Educational Options

Landfill owners/operators should continue to be advised of the benefits of landfill monitoring and the necessity for implementation of corrective measures when pollutants are found to be discharging from their sites. More frequent testing of groundwater monitoring wells for mercury could be implemented through the NJPDES-DGW testing requirements for the closed landfill sites.

Recommendations

- Minimize discharges of leachate to the surrounding environment from closed landfills.
- Monitor groundwater wells at solid waste landfills under the NJPDES-DGW program.
- Educate landfill owners on the benefits of landfill monitoring and the necessity for implementing corrective measures.

Municipal Solid Waste Combustion

Identification and Description of Source

Solid waste is broadly divided into two major components - Municipal Solid Waste (MSW) and Bulk and Industrial Solid Waste (B/ISW). MSW is generated by residential, commercial and institutional sources within a community. B/ISW is solid waste that cannot be compacted such as tree trunks, appliances (white goods & brown goods), vehicles, scrap metals, construction/demolition waste, and tires. B/ISW also includes residual wastes such as petroleum-contaminated solids, water treatment residues and combustion ash residues. In 1999, 17.2 million tons of solid waste was generated in New Jersey. Table 1 shows 1999 New Jersey solid waste quantities by management method.[213] Much of the tonnage of recycled waste is ferrous metals (e.g., scrapped automobiles) and building demolition and related debris.

Table 1.
New Jersey 1999 Solid Waste Quantities by Management Method

Management method	**Millions of tons**
Recycled (total)	**9.5**[214]
Disposed, incineration	*2.1*
Disposed, in-state landfill	*3.3*
Disposed, out-of-state	*2.7*
Disposed (total)	**7.6**

The composition of the solid waste for disposal in an MSW incinerator is approximately 95 percent MSW and 5 percent processible BISW. The majority of the BISW, which is not recycled, is landfilled. The majority of solid waste exported for disposal is landfilled.

---

[213] The generation data is developed from an aggregation of sources including county weighing/composition studies and USEPA national data. This data is reconciled based on the reporting data for recycling and disposal. The disposal data is developed from the solid waste disposal facility monthly reporting as required in the Solid Waste Regulation at NJAC 7:26. As required, each truck that disposes of waste at a solid waste facility (including transfer stations) must submit an origin and destination (O&D) form which lists the waste types and municipality(s) of origin of the waste. All solid waste disposal facilities have weigh scales and are required to report by waste type, municipality and tonnage. The recycling data is developed from municipalities and end markets reporting. All municipalities are required to report the materials and tonnage of solid waste recycling on an annual basis. This information is supplemented by reporting from the end markets, including the processing or materials recovery facilities. The annual recycling reports are audited by NJDEP. The municipal and county recycling rates are adjusted based on recycling that occurs statewide and is apportioned to the counties.

[214] Much of the tonnage of recycled waste is metals, e.g. scrapped automobiles (1.2 million tons), building and construction demolition and related debris (5.0 million tons), yard waste (1.3 million tons), and various paper grades (1.3 million tons).

MSW contains an estimated 2 ± 0.5 ppm of mercury[215] (see separate write-up on Solid Waste Deposited in Landfills, elsewhere in this document). When this waste is incinerated, some of the mercury contained in the waste is released to the atmosphere.

Quantity and Estimated Uncertainty

The high temperatures involved in the solid waste incineration process (in the range of 2000° F) can be expected to vaporize virtually all of the mercury present in the waste, regardless of chemical species. Current emission controls on New Jersey solid waste incinerators, which primarily consist of the injection of finely-divided carbon into the particulate control mechanism, remove an estimated 95% or more of the mercury from the combustion exhaust gas stream. The injected carbon is ultimately mixed with the ash. Work by the first New Jersey mercury task force indicates that mercury appears to remain adsorbed on the injected carbon and that mercury releases from municipal solid waste combustion ash are low.[216]

Over the past decade, due to NJDEP requirements[217] that were implemented as a result of the efforts of New Jersey's first Mercury Task Force,[218] these incinerators have installed the carbon injection emission controls noted above. It is also likely that, during this period, the mercury content of MSW has declined due to the virtual elimination of mercury in dry cell batteries, packaging, and other items due to New Jersey laws,[219] national laws, and voluntary reductions of mercury content by manufacturers of some mercury-containing items.[220]

New Jersey's five MSW incinerators are required to report results of stack tests of the mercury concentration of the emitted gas stream on at least a yearly basis. These results are converted to pounds-per-year estimates of mercury emissions. These estimates provide evidence of a consistent and dramatic decline in mercury emissions over the past decade, as shown in Table 2.

---

[215] There are two sources of data useful for determining the mercury content of MSW in New Jersey. One source is information on the mercury content of MSW combustion ash; the other is the mercury content of the inlet gas stream at MSW combustion facilities. There is some inconsistency among these data and the resulting calculated mercury content of MSW. The inconsistency may be the result of incomplete volatilization of some mercury-containing items in the MSW waste stream, or variations among the sampling and testing procedures. Overall, a mercury content in the range of 1.5 to 2.5 ppm appears likely.

[216] New Jersey Department of Environmental Protection & Energy, 1993, *Task Force on Mercury Emissions Standard Setting, Final Report on Municipal Solid Waste Incineration, Volume III, Technical and Regulatory Issues*, Chapter 11, Environmental Effects of Mercury Control on the Solid Waste Stream, pp. 11.1 to 11.10, NJDEP, Trenton, NJ, July, 1993.

[217] See, especially, N.J.A.C. 7:27-27.4.

[218] NJDEP, 1993, *Task Force on Mercury Emissions Standard Setting, Final Report on Municipal Solid Waste Incineration*, NJDEP (at that time, NJDEPE), July, 1993.

[219] Especially, the Dry Cell Battery Management Act, N.J.S.A., 13:1E-99.59 through 13:1E-99.81, and the Toxic Packaging Reduction Act, N.J.S.A. 13:1E-99.44 et seq.

[220] As an example, the mercury content in a Philips low mercury fluorescent lamp is 3 mg of mercury per 4-foot lamp. The current industry-reported average is in the range of 10 mg per 4-foot lamp. This industry average has been reduced from 80 mg per 4-foot lamp over the last 10 years.

Table 2.
Estimated Mercury Emissions from MSW Incineration, Pounds Per Year, 1991 Through 1999

Facility	**Facility capacity, tons/year**	**1991,'92,'93**	**1996**	**1997**	**1998**	**1999**
Camden	451,140	1084	431	350	144	113
Essex	985,500	1771	216	323	115	162
Gloucester	209,875	149	32	51	25	15
Union	562,100	844	84	42	24	32
Warren	160,000	562	4	4	3	4
Total		**4410**	**767**	**770**	**311**	**326**

Historically, solid waste has been incinerated in large quantities in urban areas. For example, from the 1920s through the 1970s, quantities in the range of 1 to 1.5 million tons of solid waste were burned each year in the New York metropolitan area.[221] Comparable quantities were likely burned in the Philadelphia area. It can be assumed, based on historical uses of mercury, that this waste contained a quantity of mercury similar to waste today. Because the incineration technology used up to the 1970s had very limited controls on emissions, including particulate emissions, it can be assumed that virtually all of the mercury contained in the incinerated waste was emitted. Much of this mercury emission, which was likely in the range of at least 5000 pounds per year in the New York region alone,[222] could have been deposited relatively close to the sources, which were typically relatively small municipal incinerators and small units in apartment and institutional buildings.

The large reduction in emissions from the solid waste incineration sector that have been achieved over the last decade have lowered the emission to the present estimate of about 300 pounds per year. The magnitude of this reduction provides encouragement that other combustion and combustion-related sources can achieve a similar degree of control.

Sectors Affected

Solid waste incinerators are potentially affected by any additional measures to reduce emissions from this sector. Since all sectors (residential, commercial, industrial, etc.) generate waste, all would be affected as well.

Receiving Media

The receiving medium for the emissions from MSW incinerators is initially air followed by water/land deposition. The residual ash, including bottom ash, grate ash, boiler ash pollution control residue and fly ash (known as combined ash from MSW incinerators) is disposed at

---

[221] Chillrud, Steven, R. Bopp, et al., 1999, Twentieth century atmospheric metal fluxes into Central Park Lake, New York City, *Env. Sci. Technol. 33*, 657-662.

[222] 1 million tons at 2.5 ppm = 2.5 tons, or 5000 lbs.

MSW landfills. The MSW landfills are currently designed with liners and leachate collection systems to hydraulically isolate the landfill from the groundwater. Some MSW landfills are constructed with double liners for leak detention and redundancy in the groundwater protection systems. Others are constructed with composite liners (including both clay and geomembrances) or double composite liners depending on their hydrogeologic location. Most of these landfills discharge the leachate to publicly owned treatment works (POTWs).

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particulates are present. Particulate controls on MSW incinerators remove most particulates.

Reduction Options and Associated Costs and Impediments

Any measures to reduce the mercury content of products will eventually result in a decrease in the mercury content of wastes, which will in turn reduce emissions from MSW incineration. There is a time lag, however, because the useful life of many products is several years or more. See the options discussed in the separate section on mercury-containing products in general use

In the meantime, New Jersey will continue to incinerate at least 25 percent of MSW disposed in the state, and emissions will continue, probably in the range of 300 lbs. per year or more, based on New Jersey's incineration capacity.

Source separation is one option for reducing air emissions of mercury from MSW incinerators. Further steps could be taken to remove mercury-containing items, such as fluorescent tubes, thermostats, and batteries from waste. A municipality, county or the state could ban certain mercury-containing products from disposal or determine them to be a mandatory recyclable material. Alternatively, waste containing mercury could be directed to a landfill rather than to MSW incinerators.

Unfortunately, due to recent court decisions related to State-mandated waste flow, New Jersey no longer has the degree of authority it once had over the flow of solid waste within its borders. A significant volume of solid waste destined for MSW incinerators is received from out-of-district and out-of state sources. Given the economics of disposal, the importation of out-of-district waste may increase.

Without effective waste flow control, a requirement that mercury-containing products should not be incinerated and should only be landfilled will be difficult to implement because New Jersey cannot require communities outside of the State to implement source separation practices. Further, even when the waste flow can be controlled sufficiently, the cost of operating an effective source separation program is high[223], although perhaps not as high as mercury

---

[223] For example, the average cost including transportation to operate a household and small business hazardous waste source separation program appears to be approximately $0.25/pound The average cost to operate a pilot curbside/dropoff demanufacturing program for consumer

emissions controls.

While waste separated from disposal and accumulated for separate management may be classified as hazardous waste, the NJDEP has classified some of these waste streams as Universal Waste in accordance with USEPA hazardous waste regulations. This limited exemption from complete hazardous waste regulations is intended to encourage recycling and, means that separated discarded mercury-containing products such as mercury switches, fluorescent lamps, and thermostats can be managed properly without full hazardous waste manifesting and reporting requirements. See separate section on Fluorescent Lamp for more details on New Jersey's Universal Waste Rule.

Further reductions resulting from improvements in emissions control techniques may also be possible.

Research, Development, and Monitoring Options

Monitoring of the inlet stack gas mercury concentrations at all New Jersey MSW incinerators, and monitoring of the total mercury concentration in the ash at two MSW incinerators (Warren County and Essex County) should continue. The data resulting from these monitoring efforts can be used to estimate the concentration of metals in MSW to determine if levels are declining, as expected due to minimization efforts and disposal trends. Current testing protocols should be fully assessed to determine if they are comprehensive.

Outreach and Educational Options

Educating the consumer on the importance of the proper post-consumer-use management of mercury-containing products is recommended. This may be done as previously mentioned through product information. However, the Department may want to consider informing and educating consumers by the use of general awareness publications and/or via the Department's web page.

Recommendations

- Consider revising the State's air pollution control regulation governing Municipal Solid Waste Incinerator (MSWI) emissions to include U.S. EPA's higher efficiency requirement for post-combustion emissions controls, thereby changing New Jersey's alternative limit based on efficiency from 80% to 85%. The 28μg/dscm primary requirement would remain the same.
- Support legislation that will reduce mercury in products sold and used in New Jersey when mercury-free substitutes are available.

---

electronics in Union County including transportation is $0.17/pound. Disposal costs are approximately $0.025 to 0.050/pound for the tip fee at the facility and $0.025/pound for collection, handling and transportation costs. The cost to handle special waste separately from the disposal stream is approximately an order of magnitude higher than disposal.

- Require source separation for MSW destined for MSW incinerators.
- Use government purchasing contracts to encourage manufacturers to produce and market low-mercury products.
- Support and fund pilot mercury source separation projects.
- Educate the public about the importance of disposing mercury-containing products and household stockpiles of mercury through household hazardous waste collection.

Municipal Solid Waste Deposited in Landfills

Identification and Description of Source

Mercury is present in the solid waste that is disposed of in sanitary landfills. Much of this mercury was intentionally added to products during their manufacture.

Quantity and Estimated Uncertainty

It has been projected that the total yearly discards of mercury in the U.S. municipal solid waste (MSW) stream in the year 1995 would be about 245 tons, declining to about 173 tons by the year 2000.[224] About 160 million tons of MSW are generated yearly.[225] Assuming that the waste generation quantity has stayed relatively constant during the period, the MSW mercury content would have been about 1.5 ppm in 1995, and about 1.1 ppm by 2000.

Estimates based on New Jersey-specific data are comparable, but suggest a somewhat higher concentration, in the range of 2 ± 0.5 ppm.[226] In 1997, New Jersey generated 16.9 million tons of MSW. Of that amount, 10.3 million tons were recycled and 6.6 million tons were disposed. Of the disposed amount, 2.6 million tons were sent to in-state landfills, 1.6 million tons were incinerated, and 2.4 million tons were disposed out-of-state.[227] Another 0.7 million tons of waste was imported and incinerated. Approximately 65% of the ash from incineration is disposed out-of-state,[228] so, overall, perhaps the mercury represented by 3.4 million tons of MSW is disposed in New Jersey landfills. At two ppm, this translates to about 13.6 thousand pounds of mercury. Another 3.9 million tons of waste (and ash of this waste) representing another approximately 15.6 thousand pounds of mercury, is disposed of out-of-state per year. The uncertainty in the mercury concentration of the waste of perhaps plus or minus 0.5 ppm suggests that the total mercury sent to disposal sites both in-state and out-of-state could range from 22 to 35 thousand pounds, with a mid-point estimate of 29 thousand pounds.

Sectors Affected

Waste disposal contractors and waste management and disposal facilities could be affected by any measures targeting this sector.

---

[224] USEPA, 1992, *Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000*, EPA530-%-92-013, USEPA, Solid Waste and Emergency Response, Washington, D.C.

[225] Office of Technology Assessment, U.S. Congress, 1989, *Facing America's Trash: What Next for Municipal Solid Waste*, OTA-O-424, p., 3, U.S. Government Printing Office, Washington, D.C.

[226] There are two sources of data useful for determining the mercury content of MSW in New Jersey. One source is information on the mercury content of MSW combustion ash; the other is the mercury content of the inlet gas stream at MSW combustion facilities. There is some inconsistency among these data and the resulting calculated mercury content of MSW. The inconsistency may be the result of incomplete volatilization of some mercury-containing items in the MSW waste stream, or variations among the sampling and testing procedures. Overall, a mercury content in the range of 1.5 to 2.5 ppm appears likely.

[227] NJDEP, Division of Solid and Hazardous Waste, January, 2000.

[228] NJDEP, Division of Solid and Hazardous Waste, June, 2000.

Receiving Media

Only a tiny fraction of the mercury deposited in landfills appears to be released in landfill gas and leachate flows. The primary receiving medium is the land surface that constitutes the disposal sites. Sites receiving waste today are engineered and managed to effectively sequester waste and minimize the movement of any of the waste's degradation products to the environment (e.g., leachate capture and treatment). Existing stack test and leachate data (see separate write-ups on landfill air and leachate emissions) indicate that, for mercury, sequestration at disposal sites is efficient.

Chemical Species

Species of mercury in waste can be expected to include all forms in which mercury is found in products, including elemental and divalent. Based on the relatively low emission of mercury from landfills, it is possible that mercury is converted to insoluble, relatively non-volatile forms, such as mercury sulfide, HgS, in the landfill environment. In landfills, the typical presence of anaerobic conditions and hydrogen sulfide, H_2S, could encourage such conversion.

Reduction Options and Associated Costs and Impediments

Any measures to reduce the mercury content of products will eventually result in a decrease in the mercury content of wastes. There is a time lag, however, because the useful life of many products is several years or more.

Research, Development, and Monitoring Options

Over the long term, the mercury content of solid waste may be a useful indicator of the decline of mercury use in products. The mercury content of MSW can be approximately estimated by stack tests of influent gas at MSW incinerators and analyses of the mercury content of MSW ash. These analyses, currently performed pursuant to NJDEP permits, should continue.

Outreach and Educational Options

None appear necessary, other than the general recommendation to communicate the importance of reducing or eliminating the mercury content of products.

Recommendations

- Reduce mercury deposited in landfills as addressed in the Mercury in Products recommendations.
- Continue to manage and monitor landfills and upgrade controls on releases from both operating and closed facilities.
- Educate the public about the importance of disposing of mercury-containing products and household stockpiles of mercury through household hazardous waste collection.

Sludge Management: Incineration, Land Application, and Disposal

Identification and Description of Source

Sludge is produced as a byproduct of the treatment of wastewater by sewage treatment plants. Most of the larger plants in New Jersey are publicly-owned, and are termed publicly-owned treatment works (POTWs). Mercury bioaccumulates in the sludge, which is the semi-solid residual byproduct of the wastewater treatment process. Typically, sludge is a combination of organic and inorganic materials and spent micro-organisms used in the treatment process, and can be expected to contain most of the bioaccumulative pollutants entering a POTW. The standard measure of sludge is in dry pounds or dry tons, and represents only the solids content of the residual remaining after treatment of wastewater. Without some form of processing, raw sludge consists of between 92% and 99% liquid.

This sludge typically contains mercury in the parts per million (mg/kg) range. POTWs are a passive recipient of mercury from outside residential, commercial, and industrial source activities. Under existing authority, POTWs can help reduce influent mercury by limiting concentrations in incoming wastewater streams through the establishment of technically-based local pretreatment limits, which they can impose if they themselves are in violation of some standard.

Quantity and Estimated Uncertainty

In 1997, about 200 lbs. of mercury were emitted to the air from the incineration of sludge based on the mercury concentration of incinerated sludge and quantities incinerated. This quantity assumes that at that time 10 New Jersey POTWs incinerated sludge, and that they all emit at a rate proportional to a subgroup of 8 POTWs that are reported to emit approximately 160 pounds of mercury through incineration.[229] About 270 pounds of mercury is in the sludge that is land applied in NJ.[230] It is estimated that about 28% of New Jersey's sludge is shipped out of state for land application, and 6% is shipped out of state for disposal.[231] It can be assumed that exported sludge slated for land application has a mercury content similar to that used in-state in the same manner. This suggests a mercury content of approximately 200 pounds in this sludge. Sludge slated for out of state disposal probably contains a similar concentration of mercury.[232] The estimated 6% of sludge disposed out of state thus could be expected to contain 50 to 100 pounds of mercury.

The total of the subgroups listed above is approximately 750 pounds, as shown in Table 1.

---

[229] Letter from Bob Dixon, Executive Director, Gloucester County Utilities Authority, April 14, 1998.

[230] NJDEP Bureau of Pretreatment and Residuals, 7/26/99.

[231] NJDEP Bureau of Pretreatment and Residuals (BPR), personal communication, 7/99.

[232] Standards POTWs must meet for a variety of parameters are believed to result in consistent concentrations of mercury in sludge, regardless of its disposal category.

Table 1.

Mercury in NJ Sludge; Estimate Quantities, by Management Method

Management method	Yearly mercury quantity (pounds)
Incineration	200
Land-applied in NJ	270 (includes some sludge generated out-of-state)
Land-applied out-of-state	200
Disposed out-of-state	75
Total	745

A higher quantity of mercury, approximately 1280 pounds, is estimated by multiplying the estimated weighted average[233] mercury concentration of New Jersey sludge (2.3 ppm) by the total quantity of sludge generated (278,900 dry tons in 1997[234]). This 1280 pound value is probably an overestimate, since the weighted average calculation includes values that were below the detection limit but were assumed to be present at a concentration equal to the detection limit. The total quantity of sludge produced may also represent some double-counting because all treatment plants test their sludge for mercury and report the concentration values and quantities, but most plants then send their sludge to another plant for final processing. The second plant again tests for mercury and reports the quantities and concentrations. These several sources of uncertainty are more likely to lead to an overestimation of the total mercury quantity than an underestimation. Therefore, a reasonable estimate is that the total quantity of mercury in New Jersey sludge is about 750 pounds, and is not likely more than about 1000 pounds.

Sectors Affected

Wastewater treatment plants, most of which are publicly owned, would potentially be affected by programs that sought to limit the amount of mercury passing through and subsequently released, either in sludge, wastewater outflow, or air emissions. Many of New Jersey's treatment plants report concentrations of mercury in their sludge at or near the detection limit. However, several treatment plants, including several that incinerate sludge, have reported mercury concentrations at 5 ppm or higher. Based on the calculations discussed above used to develop a weighted average of New Jersey sludge mercury concentration, some treatment plants appear to contribute a disproportionate share of the overall sludge mercury burden. This may be because these plants accept influent from sources with relatively high mercury discharges. Conceivably, it could be that some plants also process wastewater that is contaminated with mercury that is actually

---

[233] Developed by weighting the mean sludge mercury concentration for each reporting treatment plant, based on 1997 mercury concentration data. The plant's reported flow; based on 1999 flow data, was used as the weighting factor. Data was provided by the NJDEP Bureau of Pretreatment and Residuals.

[234] NJDEP Bureau of Pretreatment and Residuals.

present in the source (potable) water in that service area. However, it is unlikely that source water could supply more than 130 pounds of the approximately 1000 pounds per year of mercury estimated to be present in wastewater treatment sludge.[235]

Receiving Media

Management of sludge containing mercury has the potential to impact more than one medium. Below is an attempt to define primary and secondary environmental media that are/could be impacted by management method.

Management Method	Primary Medium	Secondary Medium
Land Application	Land	Surface/Ground Water/Air
Composting	Land	Surface/Ground Water/Air
Conversion To Usable Product	Land	Surface/Ground Water/Air
Incineration	Air	Land/Surface Water
Landfilling	Land	Surface/Ground Water/Air

Chemical Species

Mercury concentrations reported in sludge represent total mercury. It is likely that much of the mercury present in wastewater discharges is present in the divalent (Hg^{++}) form, since other forms are not as soluble. There could be some mercury that is associated with suspended solids in the effluent. In one study, methyl mercury was found in effluent water. (See separate write-up on wastewater discharges.) Mercury species in air emissions from incinerated sludge may be similar to those from other combustion sources. Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particulates are present. There have been suggestions that wastewater treatment plants may have gaseous emissions that contain mercury, both elemental and methyl mercury. The peer-reviewed literature indicates that methyl mercury can be produced in sewage treatment plants, and also that various forms of mercury are released to the atmosphere. *Soldano* et al. found high levels of atmospheric mercury (both organic and elemental) near sewage treatment plants.[236] *Goldstone* et al. found that under some conditions,

---

[235] As reported by Eileen Murphy, of the NJDEP Division of Science, Research, and Technology, a study of background mercury concentrations in both ground and surface waters in New Jersey indicates that 40 ng/l (ppb) is the maximum mercury concentration likely to be encountered in these waters. Drinking water purveyors in NJ must report mercury concentrations, and several have at times reported mercury concentrations above the 2 μg/l limit. However, the problem associated with interpreting sample results that are typically at or below the detection limit argues that the 40 ng/l value should be considered a reasonable upper-bound estimate. Multiplying this value by the 1054 million gallons per day wastewater flow as reported by the NJDEP Bureau of Pretreatment and Residuals indicates a maximum mercury inflow to wastewater treatment plants in source water of approximately 130 pounds per year.

[236] Soldano, B. A., Bien, P. and Kwan, P., Air-Borne Organo-Mercury and Elemental Mercury Emissions with Emphasis on Central Sewage Facilities, *Atmospheric Environment* 9:941-944, 1975.

methyl mercury is produced during the sewage treatment process.[237] *Gilmour and Bloom* studied a municipal sewage treatment plant in which elemental mercury was used as a seal in three trickling filter center columns. They found that the columns were net sources of mercury, and they found significant de novo production of methyl mercury.[238]

Reduction Options

The median mercury concentration in sludge has dropped nearly 50% over the past 15 years.[239] Although data are not readily available to pinpoint all reasons for this decline, the following actions have apparently played a significant role:

- The Industrial Pretreatment Program has reduced the amount of mercury and other pollutants allowed to be discharged from permitted industries to POTWs.

- The Pollution Prevention Program has provided industries with incentives to reduce the amounts of regulated waste produced through process changes and/or substitution to non-regulated raw materials.

- Mercury has been removed from household products (e.g., latex paint) that often found their way into POTW collection/treatment systems.

- More stringent clean up and spill reporting procedures for mercury spills/breakage for sources ranging from schools to research facilities have been implemented.

- Other products and/or technologies have gradually been substituted for historically mercury-based products, e.g., electronic thermometers, blood pressure measuring instruments, etc.

Reduction Options: Source Reduction and Pollution Prevention

- Phase out use of mercury-containing amalgam for dental fillings coupled with drain traps until phase out is complete.

- Develop a public education program among identified cultural/ethnic groups to reduce use of mercury in ceremonial and/or cultural practices.

- Increase public awareness programs to all medical practitioners, medical institutions, research facilities, educational facilities/institutions and testing laboratories, stressing the proper clean-up of breakage and spills as well as proper handling methods.

---

[237] Goldstone, M. E., et al., The Behaviour of Heavy Metals During Waste Water Treatment: Mercury and Arsenic, *Sci. Tot. Envir. 95*:271-294, 1990.

[238] Gilmour, C. C. and Bloom, N. S., A Case Study of Mercury and Methylmercury Dynamics in a Hg-Contaminated Municipal Waste Water Treatment Plant. *Water, Soil and Air Pollution 80*:799-803, 1995.

[239] Based on historical data provided by NJDEP Bureau of Pretreatment and Residuals, 1999.

- Phase out use of mercury in other products that could find their way into wastewater.
- Develop a central clearinghouse to keep abreast of national and international developments that chronicle the elimination, substitution, or reduction of mercury in products or processes. Provide this information to appropriate in-state end users.

Reduction Options: Control and Treatment of Emissions

Nationally, there is a downward trend in the use of mercury in products, with many uses having been discontinued over the last two decades. It is believed that this trend will continue. Source reduction options such as those discussed above should ensure the continuation of the downward trend in the use of mercury in products, which should translate to a declining concentration of mercury in sludge. For these reasons, it is believed that the reduction options below can be achieved with a minimum of difficulty. The purpose of the reduction options is not to force the shut -down of non-compliant facilities, but to guide facilities to reduce mercury concentrations to levels that are technologically feasible and that are consistent with levels other similar facilities have achieved.

- A concentration limit of 5 ppm, measured with a 12-month rolling average, can be applied to all sludge generated in New Jersey, by a date five years from the present, with a goal of 2 ppm, measured with a 12-month rolling average, within ten years. Limits on mercury discharges to treatment plants, perhaps with extensions of already successful pre-treatment programs to commercial and other facilities with significant mercury concentrations in their wastewater, could be expected to facilitate reductions in sludge concentrations sufficient to meet these levels.
- If, by a date five years from the present, sludge generated by a POTW is not below 2 ppm, measured with a 12-month rolling average, that POTW should evaluate and implement further pre-treatment measures and report on the results annually to the Department. Provision of additional legal authorities to POTWs, if necessary to implement the additional pre-treatment measures, should be considered.
- After ten years, should any facility incinerate wastewater treatment sludge for which the 12-month rolling average mercury concentration exceeds the 2 ppm threshold, a 100 μg/dscm standard for stack emissions, as recommended by the New England Governors' Association, may apply as an alternative standard.
- Additional legal authority should be provided to POTWs if needed to implement the mercury reduction strategies suggested above.
- Cost will be considered as a factor in determining the need for additional control equipment. The effectiveness of controlling mercury emissions from different source types of mercury emissions will be compared and considered.

Reduction Options: Research, Development, and Monitoring:

- Review new or revised risk assessment data for mercury exposure by pathway, and revise, if appropriate, standards for mercury content of wastewater treatment plant sludge by management method based on pathway of concern.

- Obtain a better understanding of the fate and transport of mercury in the land application of sludge.

- Obtain a better understanding of the species of mercury present in the various types of discharges, including sludge, sludge incinerator emissions, wastewater discharges, and air emissions from wastewater treatment plants.

Reduction Options: Costs, Difficulties, and Impediments

The suggested source reduction and pollution prevention opportunities for reducing the amount of mercury reaching POTWs collection and treatment facilities are not estimated to be overly expensive on an annual basis. Most efforts will have to be sustained over extended periods of time to be effective, however.

Depending on the control strategy adopted, the costs involved with end-of-pipe controls could be substantial, and would fall entirely on POTWs.

The costs of obtaining data on the species of mercury in the various media could be substantial. Speciation data could validate the existing assumptions used for sludge mercury standards development or could assist in determining the necessity for revision of the current standards for mercury in sludge.

Recommendations

- Increase public awareness programs regarding the use of mercury in products that find their way into wastewater.
- Identify and phase out the use of mercury in other products that could find their way into wastewater.
- Reduce the use of mercury-containing amalgam through a public education and awareness program, and phase out the use of mercury-containing amalgam for dental fillings.
- Control mercury discharges from dental offices through the use of drain traps.
- Develop an effective public education program to reduce the use of mercury in cultural practices.
- Develop a central clearinghouse to keep abreast of national and international developments; provide this information to appropriate in-state end users.
- A concentration limit of 5ppm, measured with a 12-month rolling average, can be applied to all sludge generated in New Jersey, by a date five years from the present.
- After 5 years, implement a goal of a concentration limit of 2ppm measured with a 12-month rolling average on all sludge generated in New Jersey.

- After 10 years, if sludge exceeds 2 ppm from a facility, measured with a 12-month rolling average, apply an alternate standard of 100μg/dscm for stack emissions.
- Provide POTW's with additional legal authority to implement mercury reduction strategies.
- Review risk assessment data for mercury exposure by pathway and revise mercury content standard for wastewater treatment plant sludge, as appropriate.
- Study the fate and transport of mercury in land application of sludge to develop a better understanding.
- Obtain a better understanding of the species of mercury present in the various types of discharges from wastewater treatment plants.

Soils, Contaminated: Thermal Treatment

Identification and Description of Source

The cleanup of oil-contaminated soil sometimes is done in a device which involves the heating of the soil to drive off the organic matter. This can be done in the temperature range of 400° F (low temperature thermal desorption) to 2000° F (incineration). In either case most, or all, the mercury is driven off, as well as the organic matter.

There are four low temperature thermal desorption (LTTD) units permitted to operate in New Jersey, including 3 commercial units and one dedicated on-site soil cleanup unit. (Others that have operated in the past ten years for site cleanups, but which are not currently operating include the Bog Creek Superfund site, Ocean County, BROS Superfund site, Logan Township, Ryan Murphy LTTD Mercer County for the New Jersey Turnpike petroleum contaminated soils, and the Lipari Superfund Site.)

Quantity and Estimated Uncertainty

Stack testing has been done on 3 of the 4 units. Emissions ranged from 2 to 240 pounds per year per unit if operated at maximum permitted soil throughput and the most recent stack test data is used. Initial tests, conducted 9/98, at one unit (Merck) equated to 138 pounds per year, but improvements in the carbon injection control system reduced annual emissions to about 2 pounds per year (6/99 tests). For this reason, the total emission potential from these 4 units is estimated at approximately 80 pounds per year. However, one unit was not tested for mercury and the others have few tests, so this is an uncertain estimate. LTTD units used for short term (less then 1 year) are not included in the estimate. Also, one of the units (Casie) is working to reduce mercury emissions by testing carbon injection under an Administrative Consent Order. If as successful as the Merck Rahway site, which only treats contaminated soils found on-site, the emissions from this unit should drop to under 5 lbs. per year. Therefore, the annual emission estimate for this source category would be less than 50 pounds per year.

Sectors Affected

Three commercial and one on site cleanup unit for soil currently operate in NJ. Other units could also be permitted.

Receiving Media

The chief receiving medium is air, unless carbon is used, in which case captured mercury on the carbon is usually disposed of in a landfill. See the separate source write ups "Landfill Gas" and "Landfill Leachate" elsewhere in this document.

Chemical Species

Limited estimates of the species of mercury emitted from combustion sources suggest that elemental mercury, oxidized gaseous species, such as $HgCl_2$, and species bound to particles are present. Since the units described herein operate at lower temperatures, it is expected that oxidized species and species bound to particles would be found in lower quantities, and that elemental mercury could be the dominant species.

Reduction Options and Associated Costs and Impediments

Determine important control device operating parameters and set requirements to minimize mercury emissions, consistent with the significant reductions (about 98%) achieved for the Merck unit.

Require carbon injection, or equivalent control, for units emitting significant mercury emissions (i.e. over 10 pounds per year). Consider setting a uniform mercury emission standard for LTTD units.

Research, Development, and Monitoring Options

Test the one unit (Earle Environmental) which has not been tested for mercury emissions.

Require periodic testing of all LTTD units.

Outreach and Educational Options

None are suggested.

Recommendations

- Determine important operating control parameters and set operating parameter requirements to minimize mercury emissions.
- Require carbon injection or equivalent control.
- Consider settling a uniform mercury emission standard for thermal treatment units.
- Test the one remaining unit that has not been tested for mercury emissions.
- Require periodic testing of thermal treatment units.

Wastewater

Identification and Description of Source

Wastewater is generated by households, institutions, commercial facilities, and industrial operations. In New Jersey, most wastewater is discharged to sewage treatment facilities, although some is discharged directly to ground water and surface water. These discharges contain some mercury, although the concentrations are typically at or near the detection limit.

Quantity and Estimated Uncertainty

All facilities with permitted discharges of mercury to surface and groundwater report their discharges to NJDEP. Many of these facilities are wastewater treatment plants. Mercury loadings to both surface and ground waters, as calculated by NJDEP based on total flows and discharge monitoring reports (DMRs) submitted for 1998, were approximately 820 pounds.[240] About 15% of the New Jersey population is unsewered.[241] Some of the unsewered discharges are included in the DMRs submitted to the NJDEP, but most are not. With the assumption that 15% of the total mercury discharge in wastewater is unaccounted for in the DMR data, the total mercury entrained in wastewater discharges in New Jersey is about 965 pounds.

There is uncertainty with this calculated number, because it is based on an interpretation of DMR values that are, in many cases, at or near the detection limit. The procedure of the NJDEP Bureau of Permit Management is to treat values reported as below the detection limit as being one half of the detection limit. If the detection limit value is high relative to the actual values in the wastewater being tested, the calculated mercury quantity could be an overestimate. If the detection limit value is low relative to the actual values, however, the calculated quantity could be an underestimate. The USEPA is reportedly developing a new analytical method for clean wastewater, method #1631, which will result in lower detection limits. If widely used by POTWs, use of this method offers the possibility of leading to a more accurate, and perhaps lower, estimate of the quantity of mercury in wastewater.[242]

The sources of mercury in wastewater are not well understood. A study carried out in Palo Alto, California suggest that much of the mercury loading comes from consumer products that are discarded in the domestic wastewater stream, as is shown in Table 1.[243] This study found the discharge from dentists' offices to be significantly higher in mercury concentration than other sources, although their flow was relatively low and so this source contributed less than 10% of the total loading. Other studies have suggested that dentists' offices probably contribute about 10% of the mercury loading,[244] and less than 25 percent of the total wastewater load.[245] The Palo

---

[240] Bureau of Permit Management, NJDEP, 4/20/99.

[241] Van der Leeden, Frits, Fred Troise, and David K. Todd, 1990, *The Water Encyclopedia, 2nd Edition*, Lewis Publishers, Chelsea, MI, 48118, p. 543.

[242] Touminen, Tim, Western Lake Superior Sanitary District, personal communication, March 20, 2000.

[243] Palo Alto Regional Water Quality Control Plant, 1997, *Mercury Source Identification*, Palo Alto Regional Water Quality Control Plant, Palo Alto, CA 94303.

[244] Massachusetts Water Resources Authority, 1997, *Mercury in Dental Facilities*, Massachusetts Water Resources Authority, Sewerage Division, Toxic Reduction and Control Department, September, 1997.

Alto study also found that over 20% of the mercury loading came from the source water. In New Jersey, a study of background mercury concentrations in both ground and surface waters[246] found that 40 ng/l (ppb) is the maximum mercury concentration likely to be encountered in these waters. Drinking water purveyors in NJ must report mercury concentrations, and several have at times reported mercury concentrations above the 2 µg/l limit. However, the problem associated with interpreting sample results that are typically at or below the detection limit argues that the 40 ng/l value should be considered a reasonable upper-bound estimate. Multiplying this value by the NJ wastewater flow going to treatment plants of 1054 million gallons per day[247] indicates a maximum mercury inflow to wastewater treatment plants in source water of approximately 130 pounds per year, nearly 15% of the total loading.

A recent report[248] suggests that source water may contribute a smaller percentage of the total mercury loading to publicly owned (wastewater) treatment works (POTWs). This report found that, in Palo Alto, source water averaged 0.9 ng/l mercury, and in the Great Lakes region source water mercury concentrations ranged between 2 and 4 ng/l. The report concluded that the relative contribution from drinking water to total wastewater mercury content appears to be small (2 to 4%).

This same report discusses a study of influent wastewater at four POTWs around the U.S. This study found that the mean mercury concentration of domestic wastewater, including all values measured, was 178 ng/l. When suspected outliers were excluded, the concentration was estimated to be 138 ng/l. This study estimated that about 10% of the mercury in domestic wastewater came from fish and shellfish consumed. Much of the remaining mercury appeared to come from loss of mercury from dental amalgams resulting from normal wear. One conclusion of this study is that a background mercury concentration averaging more than 100 ng/l can be expected in POTW wastewater influents, even if complete elimination of industrial point source discharges is accomplished. Another conclusion of the report is that loss of mercury from in-place dental amalgams may be the major source of mercury in domestic wastewater.

A background concentration of mercury in wastewater as found in the above-referenced study (approximately 150 ng/l), when multiplied by the yearly wastewater flow in New Jersey, would contribute a total in the range of 500 pounds per year to the total mercury coming into New Jersey wastewater treatment facilities. As noted above, the estimated total amount of mercury in wastewater in the state is estimated to be in the range of 965 pounds, with about 820 pounds contributed by facilities submitting discharge monitoring reports.

It should be noted that a significant portion of the mercury included in wastewater flowing into treatment plants or into septic tanks is likely to accumulate in the wastewater treatment plant sludge or the semi-solid fractions included in septage, and thus not appear in the effluent. (See

---

[245] Johnson, William and Teresa Pichay, 2001, Dentistry, Amalgam, and Pollution Prevention, CDA Journal, 29, 509-517.

[246] Eileen Murphy, NJDEP Division of Science and Research, personal communication, 12/99.

[247] NJDEP Bureau of Pretreatment and Residuals, 12/99.

[248] Association of Metropolitan Sewerage Agencies (AMSA), 2000, *Evaluation of Domestic Sources of Mercury*, AMSA, 1816 Jefferson Place, NW, Washington, DC 20036-2505.

sludge management write-up elsewhere in this document.) Adding the approximately 750 pounds of mercury leaving wastewater treatment facilities in the form of sludge gives a total of about 1500 pounds per year mercury exiting New Jersey wastewater treatment plants. Thus perhaps 1/3 of the total mercury discharge from wastewater treatment facilities may be contributed by domestic wastewater.

Table 1
Mercury Source Identification
Palo Alto, CA Regional Water Quality Control Plant

Mercury Sources	**Average Hg Concentration, (µg/l)**	**Estimated Flow (gal/year)**	**Average Hg Load (lbs./year)**
Residents	0.24	5.4 × 10^9	11
Water Supply	0.075	8.1 × 10^9	5.1
Dentists	41	6.2 × 10^6	2.1
Permitted Industries	0.19	7.0 × 10^8	1.3
Storm Water Inflow	0.28	3.1 × 10^8	0.7
Employee-Related Human Waste	NA	NA	0.7
Stanford University	0.17	4.3 × 10^8	0.6
Other Known Sources:			
Septage Haulers	62	4.5 × 10^5	0.2
Commercial Laundries	0.31	1.1 × 10^7	0.03
Portable Toilets	1.4	2.1 × 10^5	0.002
Unknown Sources	NA	NA	1.6
TOTALS	0.30	9.3 × 10^9	23

Sectors Affected

All dischargers of wastewater would potentially be affected by any programs designed to reduce the mercury loading in this source including residential, commercial (including institutional), and industrial. Dental offices could be especially affected.

Receiving Medium

The receiving medium is surface and ground water.

Chemical Species

The species of mercury in wastewater is unknown. It is likely that much of the mercury present in wastewater discharges is present in the divalent (Hg^{++}) form, since other forms are not as soluble. There could be some mercury that is associated with any suspended solids in the effluent. Water-soluble environmental mercury species include the divalent mercuric ion, Hg^{++}, mercuric chloride, $HgCl_2$, the anionic complexes HgX_3^-, HgX_4^{-2}, with $X = OH^-$, Cl^-, or Br^-, and mixed halide complexes such as $HgCl_2Br^{-}$[249] although some of the total could also be methyl mercury, CH_3Hg^+.

Reduction Options

Because wastewater mercury concentrations are typically very low relative to the volumes of wastewater, no control recommendations appear feasible, except perhaps for discharges from dental offices. Even in this case, the concentrations are low enough so that end-of-pipe treatment is not likely to be feasible. Source reductions, including the substitution of new materials for mercury dental amalgam, and also including elimination of mercury in any consumer products that contribute significantly to the domestic wastewater flow, appear to be the best options for reducing the load of mercury in wastewater. See the discussion of pollution prevention and source reductions in the sludge management write-up.

Recommendations

- Control mercury discharges from dental offices.
- Substitute new materials for mercury dental amalgam, and eliminate mercury in any consumer products that contribute significantly to the domestic wastewater flow.

---

[249] DeNoble, James P., 1999, Critical Review: *Atmospheric Methylmercury: Sources, Sinks, and Inferences for its De Novo Generation,* DRAFT Masters Thesis, Rutgers University, October, 1999.

Naturally Occurring Emissions

Identification and Description of Source

Mercury is relatively rare in the earth's crust. The dominant natural form of mercury is mercury sulfide, HgS, also known as cinnabar, an extremely insoluble compound. Mercury is emitted in trace quantities from soils and water bodies, including the ocean, in a natural cycle and much of the natural emission may be from volcanoes, with some from erosion and some from the decay of both terrestrial and marine plants.[250] Over the past 100 years, anthropogenic activities have led to the emission of approximately 200,000 tons of mercury.[251] Of this total, about 3000 tons are now in the atmosphere, about 7000 tons are in the surface ocean, and about 190,000 tons have accumulated in surface soils. These quantities have increased the "natural" emission from the surface ocean by a factor of three, although they have not appreciably changed the natural emission from surface soils.[252]

Quantity and Estimated Uncertainty

The mean natural emission of mercury from land has been estimated to be about 9.7 $\mu g/m^2/yr$.[253] Although mercury deposits occur in all types of rocks, the geologic environments that typically host mercury deposits are unlike those in the New Jersey coastal plain.[254] There are no known deposits of mercury elsewhere in New Jersey, and no volcanoes. There is no reason to believe that emissions from the land surface in New Jersey are significantly higher than the mean natural flux. With a land area of about 2,000,000 hectares, or 2×10^{10} m^2, natural emissions of mercury from New Jersey are estimated at approximately 190 kg, or 420 pounds, per year.

Both wet and dry deposition of mercury to the land surface occur. This input is discussed in Chapter 1 of Volume III. This deposition includes both natural and anthropogenic components. The present atmospheric burden of mercury is estimated to have increased by approximately a factor of three from pre-industrial times.[255] There is ample evidence that global mercury deposition rates have increased significantly over the past 150 years.[256] In one study, mercury accumulation rates in Great Lakes' sediments were found to have increased by factors ranging from 50 to over 200 from pre-industrial to modern

---

[250] Nriagu, Jerome O., 1989, A global assessment of natural sources of atmospheric trace metals, *Nature, 338*, 47-49.

[251] Fitzgerald, W., and R. Mason, 1996, The global mercury cycle: oceanic and anthropogenic aspects, in W. Baeyens, et al (eds.), *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*, 85-108, Kluwer Academic Publishers, Netherlands.

[252] Fitzgerald and Mason, 1996.

[253] Fitzgerald and Mason, 1996.

[254] Dooley, John, 1992, Natural sources of mercury in the Kirkwood-Cohansey aquifer system of the New Jersey coastal plain, New Jersey Geological Survey, Trenton, NJ, 08625.

[255] Fitzgerald, W. F., 1995, Is mercury increasing in the atmosphere? The need for an atmospheric mercury network (AMNET), *Water, Air, and Soil Pollution 80*, 245-254.

[256] Fitzgerald, William, Daniel Engstrom, Robert Mason, and Edward Nater, 1997, The Case for atmospheric mercury contamination in remote areas, *Environ. Sci. Technol, 32, 1-7.*

times.[257] Even in relatively remote areas, mercury accumulation rates appear to be 3 or more times higher now than before the industrial age.[258,259] Atmospheric deposition rates in New Jersey are generally higher than in most of the U.S,[260] even though New Jersey has no known significant natural sources. It is likely that anthropogenic sources dominate the atmospheric deposition quantity in New Jersey by at least a factor of 2, and perhaps by a factor of 50 or more.

Sectors Affected

No sectors are directly affected.

Receiving Media

The natural emissions discussed herein are to the atmosphere. Data were not found on natural emissions to or from other media. Changes in such emissions may also have resulted from human activity, although, due to the heterogeneity of aqueous and terrestrial environments compared to the atmosphere, detecting the degree of any such changes will likely be more difficult.

Chemical Species

The primary species of natural emissions is believed to be elemental mercury.

Reduction Options and Associated Costs and Impediments

Emissions of naturally-occurring mercury from soils are not likely to be affected by human activities. Reduction of anthropogenic emissions can be expected over time to reduce the current anthropogenic perturbation of the natural mercury cycle. This perturbation, as discussed elsewhere, appears to primarily affect water bodies, including the surface of the ocean.

---

[257] Pirrone, N., I. Allegrini, G. Keeler, J. Nriagu, R. Rossmann, and J. Robbins, 1998, Historical atmospheric mercury emissions and depositions in North American compared to mercury accumulations in sedimentary records, *Atmospheric Environment*, 32, 929-940.

[258] Lorey, Peter, and Charles Driscoll, 1999, Historical trends of mercury deposition in Adirondack Lakes, *Environ. Sci. Technol*, *33*, 718-722.

[259] Swain, Edward B., D. Engstrom, M. Brigham, T. Henning, and P. Brezonik, 1992, Increasing rates of atmospheric mercury deposition in mid-continental North America, *Science, 257*, 784-787.

[260] Eisenreich, S. J. and J. Reinfelder, 2001, *Interim Report to the New Jersey Department of Environmental Protection, The New Jersey Atmospheric Deposition Network (NJADN)*, Department of Environmental Sciences, Rutgers University, New Brunswick, NJ 08901.

Appendix III-A: Evaluation of Control Options for Three Source Categories

Data relevant to setting mercury emission limits includes mercury concentration, flue gas flow rate, and annual emissions. Comparisons of these parameters are provided in graph form for three source categories: coal boilers, municipal solid waste (MSW) incinerators, and iron and steel furnaces. Data indicates that coal fired utilities generally emit relatively low concentrations of mercury (ranging from 1 to 20 µg/dscm or 5 to 100 milligrams per megawatt hour (mg/MWhr)) in high flue gas flows, resulting in significant annual emissions. Mercury emissions concentrations for iron and steel industry are in the range 10 to 100 µg/dscm, which is between MSW inlet and outlet emissions, and higher than coal outlets. High gas flow also results in substantial annual mass emissions from iron and steel production. Iron and steel plants have a wide range of gas flows, as low as MSW and as high as coal combustion.

Emission Standards for Municipal Solid Waste incinerators

In 1994, NJ adopted rules to set an interim mercury emission standard of 65 µg/dscm to be met by the year 1996 and 28 µg/dscm to be achieved by the year 2000. 80% reduction was set as an alternative standard in case source separation was unsuccessful. The mercury emissions standard of 28 µg/dscm was set based on a presumption of at least 80% control with carbon injection and 80 % reduction with source separation/waste stream mercury reduction measures. Testing over the last 5 years have demonstrated that carbon injection on MSW incinerators can consistently achieve over 95% mercury reduction with baghouse particulate collection and over 90% mercury reduction with electrostatic precipitator (ESP) particulate control. Inlet mercury concentrations vary widely around a 300 µg/dscm average, which has dropped from an average of 700 µg/dscm in the early 1990's. The mercury control experience with MSW incinerators demonstrated the benefits of a good mercury waste recycling program, the superior performance of baghouse control when compared to ESP's, and increased mercury removal efficiency with increased carbon injection.

Subsequent to New Jersey's mercury emission standard, the federal EPA also adopted mercury limits. The federal 80 µg/dscm or 85% control standard did not consider mercury in waste reduction and incorporated a higher control efficiency alternative limit. Based on the demonstrated success of carbon injection, New Jersey can increase the control efficiency component of the NJ mercury standard to the federal 85% level.

New Jersey currently requires that the most effective air pollution control be used when existing control devices are replaced. Hence, MSW incinerators should replace electrostatic precipitator (ESP) particulate control with more effective baghouses at the end of the useful life of the ESP's. This will cause mercury emissions to decrease from the ESP controlled facilities over the long term.

Emission Standard Considerations for Coal Fired Boilers

Based on limited testing of NJ coal fired boilers, lower emission concentrations of mercury appear to be related to use of baghouse particulate control, wet scrubbing, selective non-catalytic reduction (SNCR), and low sulfur washed coal. Based on pilot testing, a slip stream of flue gas, carbon injection prior to particulate control devices on coal fired boilers can significantly reduce mercury emissions.

It is appropriate to consider a combination of limits for a mercury emission standard. An electrical output based component expressed as mg/MWhr limit would promote higher energy efficiency. A percent reduction component would address the wide range of uncontrolled emissions, similar to MSW. The variability of mercury concentrations from coal fired boilers appears to be the result of the variability of mercury in coal and the varying ability of the existing control systems to remove mercury. The percent reduction alternative would act as a safety value for high mercury coals and allow a reasonably low mg/MWhr primary limit (applicable to average coal) to achieve significant overall reductions. Hence, a logical format for a standard would be "X mg/MWhr or Y % reduction, whichever results in the higher emission level".

A reasonable percentage reduction of emissions with mercury control systems would likely be in the range of 75 to 90%. For large MSW incinerators, EPA incorporated 85% reduction in its mercury standards. Stack testing has demonstrated that 95% and 98% reduction can be achieved by carbon injection on MSW incinerators operating with ESPs and baghouses respectively. Since mercury from coal combustion is at lower concentration and more likely to be elemental, lower removal efficiencies are expected.

Most of the coal fired units in NJ are emitting 10 to 20 mg/MWhr of mercury. Assuming 75 % reduction, mercury emissions would be lowered to the range of "2.5 to 5 mg/MWhr". Assuming 90 % reduction, mercury emissions would be in the range of "1 to 2 mg/MWhr". Based on evaluation of these limited NJ data, an appropriate standard would likely be in the range of "1 to 5 mg/MWhr or 75 to 90% reduction". Similar to MSW regulation, the Department could adopt rules that phase in limits over time. Given the federal requirement to propose a national mercury limit by December 2003, the substantial mercury in coal and emission data being evaluated by the USEPA, and national efforts to further evaluate mercury control; it is premature for the NJ Mercury Task Force to propose a specific mercury limit at this time.

Emission Standard Considerations for the Iron and Steel Industry

Mercury emissions concentrations for iron and steel production are in the range 10 to 100 µg/dscm, which is between MSW inlet and outlet mercury concentrations, but higher than coal outlet mercury concentrations. Consequently, if it is feasible to reduce mercury emissions from MSW and coal, it should be feasible to reduce mercury emissions from iron and steel. Separation of mercury containing waste materials from MSW and reduction of mercury use in products resulted in reducing average mercury emissions by about 60%. Similarly, scrap management could significantly lower iron and steel mercury emissions, perhaps by greater amounts.

Existing air pollution control systems on iron and steel furnaces may control mercury, but the Department does not have any mercury emission data on emissions from iron and steel plants before existing particulate control. Iron and steel furnaces with baghouses could use carbon injection to significantly reduce mercury emissions, as was done with the MSW incinerators. With respect to facilities with scrubbers, the NESCAUM report dated September 2000, page IV-7, indicates some scrubbers have been observed to remove 85-95% of oxidized mercury. However, the species of mercury from iron and steel production may be primarily elemental, which is harder to catch with carbon and scrubbing. Measures to oxidize mercury may be useful to increase removal efficiency of control.

A standard in the form of percent reduction of stack outlet is inappropriate because it does not give credit for mercury reductions from existing control and would not give credit for mercury reductions from scrap management. Percent reduction for inlets to control may be feasible, but would require 2 simultaneous tests and does not promote energy efficiency or pollution prevention.

An effective concentration limit in µg/dscm or an output based limit in mg/ton of iron and steel may be feasible, but the variability of mercury in scrap would need to be addressed.

A combination of pollution prevention or percent reduction limits (mg/ton or % reduction) may be the most appropriate format for a standard. A production related limit in terms of mg/ton will be better than µg/dscm because it will promote energy efficiency and pollution prevention. The combination standard may be most reasonable for a wide range of uncontrolled emissions. The percent reduction alternative provides a flexible standard for high mercury scrap and allows a reasonably low mg/ton primary limit (applicable to average scrap) to be set in order to achieve significant overall reduction. The percent reduction (of the control system inlet) component may be most appropriate as an interim standard, and could be eliminated in the longer term. The long-term standard could be a uniform mg/ton pollution prevention standard, as mercury is eliminated from products that become scrap iron and steel. Additional mercury emission data is needed to determine the effectiveness of mercury waste separation and air pollution control systems prior to setting a specific mercury standard for iron and steel production.

Appendix III-B: Calculation of Mercury Releases from Products in Use and During the Waste Disposal Process (Not Including Fluorescent Tubes)

It is assumed that the primary species of mercury subject to volatilization is elemental mercury, which is contained in items including switches and measuring devices. Likewise, the quantity of mercury released from products that break or otherwise spill mercury during their use can also be estimated from assumptions and estimates regarding the quantities involved, and physical data for mercury.

To estimate the release due to volatilization during the waste disposal process, the following procedure was used. First, the total amount of mercury in the solid waste stream was estimated, based on the report that about 8 million tons of solid waste is generated per year[261] and with the assumption that the mercury content of this waste is 2.0 ppm.[262] It is estimated, based on waste composition and use data,[263] that 10% of the mercury in solid waste is contributed by fever thermometers, 6% is contributed by thermostats, and 1% by other items, including light switches. It was further assumed that, during disposal, 90% of the thermometers would break and release contained mercury and that 5% of the other items would break. (An additional amount of the mercury in municipal solid waste is contributed by fluorescent tubes, virtually all of which would break during disposal. See the separate section describing this source. Also, mercury present in switches, etc. in discarded automobiles can contaminate recycled metals; see separate write-ups on aluminum and aluminum scrap processing and iron and steel manufacture.) Based on the solid waste quantity, its mercury concentration, and the above waste content percentages and estimated percentage of breakage, the mercury contained in broken thermometers, thermostats, and other items in the municipal solid waste stream totals about 2900 pounds per year (1300 kg/yr.). It was then assumed that this mercury from broken items would be dispersed during the waste handling process into spheres of various diameters, and the surface area of these spheres was estimated.[264]

---

[261] NJDEP, 2000, Division of Solid and Hazardous Waste, Trenton, NJ 08625.

[262] See separate section, "Solid Waste Deposited in Landfills" in this report.

[263] USEPA, 1992, *Characterization of Products Containing Mercury in Municipal Solid Waste in the United States, 1970 to 2000*, EPA530-R-92-013, USEPA, Washington, D.C.

[264] It is assumed that the 1300 kg of mercury would be liquid that would be dispersed to a greater or lesser degree depending on how small the spheres of mercury are that form during the breaking and mixing from solid waste processing. If the spheres that form are spherical and all 1 mm in radius, each one would have a volume of 4.2 mm^3 and a surface area of 12.6 mm^2 (using the formulae that the volume of a sphere is $4\pi r^3/3$ and the surface area of a sphere is $4\pi r^2$). If the sphere is 0.1 mm in radius, each would have a volume of 0.0042 mm^3 and a surface area of 0.126 mm^2. If the spheres are 0.01 mm in radius, each would have a volume of 4.2×10^{-6} mm^3 and a surface area of 0.00126 mm^2. Mercury's density is 13.546 g/cm^3 at 20 C. 1300 kg of mercury thus would have a volume of 98,000 cm^3. If this volume was in the form of spheres of 1 mm radius, there would be about 23,000,000 of them, and their surface area would be about 2,900,000 cm^2. If the volume was in the form of spheres of 0.1 mm radius, there would be

The rate at which mercury with the estimated surface area would volatilize was then estimated, based on a series of calculations.[265] In this rate calculation its was assumed that the disposed items and the mercury entrained with them would be present in the solid waste management system for a period of two weeks. (After this time the mercury would be within a disposal site, such as a landfill or an incinerator, for which emissions are estimated and described in separate reports.) Combining the estimated rate of mercury volatilization and the estimated surface area of the mercury in the waste stream leads to an estimated release in the range of 80 pounds, per year.[266]

A similar procedure can be used to estimate the quantity of mercury released from products that break or otherwise spill mercury during their use. For this procedure, an estimate of the entire stock of mercury-containing items in use must be estimated. Such an estimate can be developed using a procedure based on various assumptions and

---

23,000,000,000 of them, with a surface area of 29,000,000 cm^2. If the volume is in the form of spheres of 0.01 mm radius, there would be 23,000,000,000,000 of them, with a surface area of 290,000,000 cm^2.

[265] Dragun, James, 1988, *The Soil Chemistry of Hazardous Materials*, Haz. Mat. Cont. Res. Institute, Silver Spring, MD, presents a formula relating the evaporation rate of a substance to that of water. The formula is:
Em = Ew(vpM * sqrt(MWm))/(vpW * sqrt(MWw)), where
Em is the evaporation rate of mercury,
Ew is the evaporation rate of water,
vpM is the vapor pressure of mercury,
MWm is the molecular wt. of mercury,
vpW is the vapor pressure of water, and
MWw is the molecular wt. of water.

The vapor pressure of Hg at 20° C is reported as 0.001201 mm Hg, and that of water is 17.535 mm Hg. The evaporation rate of water (Ew) at 70° F, with a 1 mph wind and 50% relative humidity is reported as 11.04 cm/month. (The reference for this is web site www2.nishikigoi.or.jp/bbs_a/messages/1768.html, which references a book by E.F. Schulz, *Problems in Applied Hydrology*, Colorado State University, 1976.)

Since a cm^3 of water weighs 1 gram, its evaporation rate in terms of mass per surface area would be 11.04 g/cm^2 per month. Using the formula above, Em, the evaporation rate of mercury, at these same conditions, would be 0.0025 g/cm^2 per month, or 0.00125 g/cm^2 per two week period.

[266] The surface area estimate, and the resulting volatilization estimate, is dependent on the assumed size of the spheres of mercury. With the 1 mm radius spheres, with a total surface area of 2,900,000 cm^2, 3.7 kg Hg would volatilize during a two week period. With the 0.1 mm radius spheres, with a total surface area of 29,000,000 cm^2, the volatilization would be 37 kg. With the 0.01 mm radius spheres, with a total surface area of 290,000,000 cm^2, the volatilization would be 370 kg. It is unlikely that elemental mercury would be pulverized much more finely than into spheres of 0.1 mm radius. With spheres this size, 37 kg per year, or 81 pounds per year, of the mercury contained in the waste stream from broken thermometers, thermostats, and other items including switches would volatilize on the way to disposal sites.

national data on quantities of mercury used over the past 50 years in various types of products.[267]

The first step in this procedure was to identify the national quantities of mercury used in applications where elemental mercury could conceivably be released if a product broke or the contained mercury spilled for some other reason. These uses are considered to be laboratory uses, wiring devices and switches, and measuring and control instruments. Releases from laboratory uses are discussed in another section in this document. The mercury used in wiring devices and switches was included in the "electrical, total" category until 1977. In 1978 and into the early 80s, wiring devices and switches represented about 10% of the electrical total, and it is assumed to have represented a similar percentage prior to that. Based on its share of the U.S. population, NJ is assumed to account for 3% of the national use. The estimated New Jersey quantity used for wiring devices and switches and measuring and control instruments is about 15,000 pounds per year up until the early 1980s, and declining from then to a yearly use of about 5,000 pounds by the late 1990s.

With the assumption of a 15-year half-life for this type of product, it can be estimated that the New Jersey inventory of mercury in products of this type is currently about 250,000 pounds.[268] (Approximately 20,000 pounds of mercury is estimated to be present in dental amalgam tooth fillings in the New Jersey population,[269] raising the total broad estimate of the inventory of mercury in New Jersey to nearly 300,000 pounds.)

Each year, some of this mercury in the New Jersey inventory will be removed. Most of this removed mercury, representing products discarded or recycled, will find its way to disposal sites or to recycling facilities, including facilities that recycle scrap metal. (Estimated releases from these types of sites are described separately in this document.)

---

[267] U.S. Geological Survey, various years, as described in Mercury Minerals Yearbooks for various years, formerly prepared by the U.S. Bureau of Mines and now prepared by the U.S. Geological Survey, Minerals Information, 983 National Center, Reston, VA 20192.

[268] The approximate 15,000 pound per year use can be assumed to disappear from service in a manner typical of first-order exponential degradation. With a 15-year half-life, half of an original yearly quantity would remain after 15 years, and after a period of time, a steady-state quantity would be expected to develop where the yearly loss equals the yearly input. The relationship in the steady-state situation can be expressed as $Mi = M \times k$, where Mi represents the yearly input mass, M represents the total mass in the system, and k represents the loss rate (i.e., portion of the total lost per year). With a 15-year half-life, $k \approx 0.046$ per year, and with $Mi = 15{,}000$ pounds per year, $M \approx 325{,}000$ lbs. With use declining in an approximately linear manner to a late 90s level of about 5,000 pounds per year, the current NJ inventory of mercury contained in wiring devices, switches, and measuring and control instruments, estimated numerically, is approximately 250,000 pounds.

[269] This assumes a mean weight of dental filling of 2 grams per person in New Jersey, of which 50% is mercury. This is based on the assumption that the average person has less filling material than the mean weight of filling material of a person at age of death, estimated to be 2.9 g (see write-up on Crematoria, elsewhere in this document). Multiplying 1 g by 8,000,000 (the approximate population of New Jersey) gives a total mercury quantity in in-place amalgam fillings of 8,000 kg, or about 18,000 pounds.

Some of the inventory quantity will be lost directly to the environment, however, due to breakage of items and spillage of the mercury contained.

As with the procedure used to estimate releases during waste handling described above, this spilled mercury can be assumed to form into spheres, with an approximate diameter which may vary from about 0.1 to about 1 mm. The total surface area and subsequent rate of volatilization of the mercury can then be estimated. It is assumed herein, for a first approximation, that 0.5 % of the estimated 250,000 pounds of mercury contained in wiring devices, switches and measuring and control instruments in New Jersey is lost directly due to breakage and spillage each year. This is 1250 pounds. If this mercury is represented by spheres between 1.0 and 0.1 mm in diameter, the same set of calculations used above leads to a yearly emission estimate in the range of 40 to 400 pounds per year.[270]

---

[270] The calculation procedures are the same as described in footnotes 4, 5, and 6, above, except that the quantity is 568 kg (1250 lbs.) and the mercury is assumed to volatilize for the entire year instead of a two-week period.

Appendix III-C: Calculation of Potential Mercury Air Emissions from the Land Disposal of Dredged Materials

Huan Feng
Department of Earth and Environmental Studies, Montclair State University, Upper Montclair, NJ 07043

Assumptions

1. Background information of the dredged materials from NY/NJ Harbor (NJ DEP):
    a. 6 million cubic yards of dredged material removed from New Jersey waterways each year;

    b. 75% land disposal of dredged material;

    c. 40% solid content;

    d. Total porosity: 54.7 - 56.3 v/v %;

    e. Sediment moisture content: >4%. (31% of moisture assumed in calculation);

    f. Exposed area of the storage reservoir (CDF): 30 acres.

2. Total mercury (Hg) concentration in the dredged materials:
    a. Average concentration of Hg: 2.88 mg/kg (ppm) (NJ DEP);
    b. Maximum concentration of Hg: 13.6 mg/kg (ppm) (NJDEP);
    c. Fraction of elemental Hg as total Hg: 3% (Lawson et al., 2000);
    d. Mercury concentration in the ambient air: 2.6-6.5 ng/m^3 (Eisenreich & Reinfelder, unpublished data).

3. Frequency of replenishment or refill of the dredged materials (NJDEP):
    a. Every 7 days (<u>Could be disturbed every ~ 3 days.</u>)

4. Expose time of the dredged materials to the air (NJ DEP):
    a. 7 days (<u>Could be ~ 3 days due to disturbance</u>.)

5. Wind velocity (as shown in Table 1):
    a. 5 km/hour
    b. 12 km/hour
    c. 35 km/hour

Calculations and Results

1. Amount of dredged material disposed of on land each year:
    a. 1 cubic yard = 0.765 cubic meter; dry density of dredged material = 2.65 g/cm^3;
    b. 6x10^6 cubic yard x 0.765 m^3/yd^3 x 75% land disposal x 40% solid content x 2.65 ton/m^3 = 3.65x10^6 dry tons of dredged material disposed of on land each year

2. Annual loadings of mercury to CDF along with the dredged materials each year:
    a. Average loadings of Hg = 3.65x10^6 tons x 2.88 ppm = 10.5 tons (or 10,500 kg)
    b. Maximum loadings of Hg = 3.65x10^6 tons x13.6 ppm = 49.6 tons (or 49,600 kg)

3. Potential annual average Hg emissions of Hg to the air from 30 acre CDF site:
    a. Based on 7-day and 3-day cycle periods, provided Hg concentration = 2.88 ppm.

Table III-C.1 Mercury volatilization from 30 acre CDF site (Ave Hg conc. = 2.88 ppm)

Period of a Cycle (day)	Wind Speed (km/h)	Daily Flux (μg/m2/day)	Daily Emission (g/day)	Cycle Loading (g/cycle)	Annual Loading (kg/year)	Percentage of Hg Emitted (%)
7	5	5.29	0.64	4.5	0.234	0.0047
7	12	5.82	0.71	4.95	0.258	0.0052
7	35	6.23	0.757	5.3	0.276	0.0055
3	5	7.43	0.901	2.70	0.329	0.0066
3	12	8.44	1.02	3.07	0.374	0.0075
3	35	9.25	1.124	3.37	0.41	0.0082

    b. Based on 7-day and 3-day cycle periods, provided Hg concentration = 13.6 ppm

Table III-C.2. Mercury volatilization from 30 acre CDF site (Max. Hg conc. = 13.6 ppm)

Period of a Cycle (day)	Wind Speed (km/h)	Daily Flux (μg/m2/day)	Daily Emission (g/day)	Cycle Loading (g/cycle)	Annual Loading (kg/year)	Percentage of Hg Emitted (%)
7	5	24.98	3.02	21.20	1.11	0.0047
7	12	27.48	3.35	23.38	1.22	0.0052
7	35	29.42	3.57	25.03	1.30	0.0055
3	5	35.09	4.25	12.77	1.55	0.0066
3	12	39.86	4.84	14.51	1.77	0.0075
3	35	43.70	5.31	15.92	1.94	0.0082

Comments and Suggestions:

1. The results are tabulated in Table 1. Although the dredging-spreading-lifting-compacting cycle lasts about 7 days, I also used "3 day cycle" for a reference. Because the dredged materials are frequently "disturbed" after they are put in CDF, a 3-day cycle may give you an apparent reference.

2. I made the wind speed as a variable and assumed three different wind speed conditions: calm, fair and windy, for comparison purpose.

3. As this is theoretical calculation based on the assumptions, the laboratory and field validations may be needed.

Acronyms

ACE	Army Corps of Engineers
AHA	American Hospital Association
ATSDR	Agency for Toxicology and Disease Registry
B/ISW	Bulk and industrial solid waste
BMP	Best management practices
BTU	British thermal units
CDC	Center for Disease Control
CDF	Confined disposal facilities
CEM	Continuous emissions monitoring
CESQG	Conditionally exempt small quantity generators
CPSC	Consumer Products Safety Commission
CRTK	Community Right-to-Know
DMR	Discharge Monitoring Reports
DNSC	Defense National Stockpile Center
DOE	Department of Energy
DSHW	Division of Solid and Hazardous Waste
ECOS	Environmental Council of States
EDECA	Electric Discount and Energy Competition Act
EEI	Edison Electric Institute
EPA ORD	Environmental Protection Agency Office of Research & Development
EPCRA	Emergency Planning and Community Right to Know Act
ESCO	Energy service contractors
ESP	Electrostatic precipitators
FGD	Flue gas desulphurization
GHG	Greenhouse gas
HARS	Historic Area Remediation Site
Hg	Mercury
Hg^{++}	Oxidized ionic mercury
Hg^{o}	Elemental mercury
HHW	Household hazardous waste
HID	High intensity discharge
HVAC	Heating, ventilation and air conditioning
LTTD	Low temperature thermal desorption
MCL	Maximum contaminant level
MeHg	Methylmercury
MOU	Memorandum of understanding
MSW	Municipal solid waste
MSWI	Municipal solid waste incinerator
MWC	Municipal waste combustors
MW-Hr	Megawatt hour
MWI	Medical waste incinerator
NACCHO	National Association of City/County Health Officials
NARUC	National Association of Regulatory Utility Commissioners

NASEO	National Association of State Energy Officials
NEGECP	New England Governors and Eastern Canadian Premiers
NEIWPC	Northeast Interstate Water Pollution Commission
NEMA	National Electronic Manufacturers Association
NESCAUM	Northeast States for Coordinated Air Use Management
NEWMOA	Northeast Waste Management Officials Association
NJADM	NJ Air Deposition Network
NJBPU	NJ Board of Public Utilities
NJDOT	NJ Department of Transportation
NJPDES	New Jersey Pollutant Discharge Elimination System
NJSA	NJ Statutes Annotated
NOAA	National Oceanic and Atmospheric Administration
NPO	Nonproduct output
OSHA	Occupational Safety and Health Administration
OTC	Ozone Transport Commission
PBT	Persistent, bioaccumulative, and toxic substance
PJM	Pennsylvania, New Jersey and Maryland
PMA	Phenyl mercuric acetate
POTWS	Publicly owned treatment works
ppb	parts per billion
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
RHgX	Reactive halogenated mercury
RMW	Regulated medical waste
RPPR	Release and Pollution Prevention Report
RPS	Renewable portfolio standard
SEP	Supplementary environmental project
SIC	Standard Industrial Classification
SRP	Site Remediation Program
STAPPA	State and Territorial Air Pollution Program Administrators
STAPPA/ALAPCO	State and Territorial Air Pollution Program Administrators - Association of Local Air Pollution Control Officials
TARP	Technology Acceptance and Reciprocity Partnership
TCLP	Toxicity Characteristic Leaching Procedure
TRC	Thermostat Recycling Corporation
TRI	Toxic Release Inventory
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UWR	Universal Waste Rule
WQC	Water Quality Certificate

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 2
290 BROADWAY
NEW YORK, NY 10007-1866

AUG 24 2006

GENERAL NOTICE LETTER
URGENT LEGAL MATTER
PROMPT REPLY NECESSARY
CERTIFIED MAIL-RETURN RECEIPT REQUESTED

Daryl D. Smith, President
Troy Chemical Corporation
8 Vreeland Road
P.O. Box 955
Florham Park, New Jersey 07932

RE: Diamond Alkali Superfund Site, Newark Bay Study Area
Notice of Potential Liability

Dear Mr. Smith:

The United States Environmental Protection Agency ("EPA") is charged with responding to the release and/or threatened release of hazardous substances, pollutants, and contaminants into the environment and with enforcement responsibilities under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended ("CERCLA"), 42 U.S.C. §9601 et seq. Based on the results of previous CERCLA remedial investigation activities and other environmental studies performed at the Diamond Alkali Superfund Site ("Site"), which includes the Lower Passaic River Study Area, EPA has decided to further expand the area of study to include Newark Bay and portions of the Hackensack River, the Arthur Kill, and the Kill Van Kull. This expanded area of the study is known as the Newark Bay Study Area. EPA has documented the release or threatened release of hazardous substances, pollutants and contaminants into the Newark Bay Study Area.

By this letter, EPA is notifying Troy Chemical Corporation, Inc. of its potential liability relating to the Newark Bay Study Area of the Site pursuant to Section 107(a) of CERCLA, 42 U.S.C. §9607(a). Under CERCLA, potentially responsible parties ("PRPs") include current and past owners and operators, as well as persons who arranged for the disposal or treatment of hazardous substances, or the transport of hazardous substances. Based on information that EPA evaluated during the course of its investigation, EPA believes that hazardous substances were released from

Internet Address (URL) • http://www.epa.gov
Recycled/Recyclable • Printed with Vegetable Oil Based Inks on 100% Postconsumer, Process Chlorine Free Recycled Paper

the former Troy Chemical Corporation facility located at 1 Avenue L in Newark, New Jersey, into the Newark Bay Study Area. Hazardous substances, pollutants and contaminants released from the facility into the Newark Bay Study Area present a risk to the environment and the humans who may ingest contaminated fish and shellfish. Therefore, the Troy Chemical Corporation may be potentially liable for response costs which the government may incur relating to the Newark Bay Study Area. In addition, responsible parties may be required to pay damages for injury to, destruction of, or loss of natural resources, including the cost of assessing such damages.

For the first phase of the Newark Bay Study, the EPA is proceeding with a multi-year study to determine an appropriate remediation plan for the Newark Bay Study Area. The study will involve investigation of environmental impacts and pollution sources, as well as evaluation of alternative actions, leading to recommendations of environmental remediation activities.

You are also requested to preserve and retain any documents now in your Company's or its agents' possession or control, that relate in any manner to your facility or the Site or to the liability of any person under CERCLA for response actions or response costs at or in connection with the facility or the Site, regardless of any corporate document retention policy to the contrary.

Enclosed is a list of the other PRPs who have received Notice letters. This list represents EPA's findings on the identities of PRPs to date. We are continuing efforts to locate additional PRPs who have released hazardous substances, directly or indirectly, into the Newark Bay Study Area. Exclusion from the list does not constitute a final determination by EPA concerning the liability of any party for the release or threat of release of hazardous substances into the Newark Bay Study Area. Be advised that notice of your potential liability at the Site may be forwarded to all parties on this list as well as to the Natural Resource Trustees.

We request that you participate in the EPA-approved activities underway as part of the Newark Bay Study. You, along with other such parties, will be expected to both participate in and fund this CERCLA study. For those who choose not to cooperate, EPA may apply the CERCLA enforcement process, pursuant to Sections 106(a) and 107(a) of CERCLA, 42 U.S.C. §9606(a) and §9607(a) and other laws.

In February 2004, EPA signed an Administrative Order on Consent (AOC) with Occidental Chemical Corporation (OCC) to conduct a multi-year remedial investigation/feasibility study in Newark Bay pursuant to CERCLA. This study is being conducted by Tierra Solutions, Inc. with EPA oversight. Tierra Solutions, Inc. is an affiliate of the company from which Occidental purchased Diamond Shamrock Chemicals (a former owner of a chemical plant at 80 Lister Avenue in Newark, New Jersey), and is performing the work pursuant to that company's indemnity obligation to Occidental. Be advised that notice of your potential liability is being forwarded to OCC by EPA.

We strongly encourage you to contact OCC to discuss your participation. You may do so by contacting:

Carol E. Dinkins, Esq.
Vinson & Elkins LLP
First City Tower
1001 Fannin Street, Suite 2300
Houston, TX 77002-6760
Tel. (713) 758-2528
Fax (713) 615-5311
cdinkins@velaw.com

Written notification should be provided to EPA documenting your intention to participate with OCC and settle with EPA no later than 30 calendar days from your receipt of this letter. The result of any agreement between EPA and your company will need to be memorialized in an AOC. Your written notification should be mailed to:

Amelia M. Wagner, Esq.
Assistant Regional Counsel
U.S. Environmental Protection Agency
290 Broadway, 17th Floor
New York, NY 10007-1866

Pursuant to CERCLA Section 113(k), EPA must establish an administrative record that contains documents that form the basis of EPA's decision on the selection of a response action for a site. The administrative record files along with the Site file are located at EPA's Region 2 office located at 290 Broadway, New York, NY on the 18th floor. You may call the Records Center at (212) 637-4308 to make an appointment to view the administrative record and/or the Site file for the Diamond Alkali Site, Newark Bay.

Inquiries by counsel or inquiries of a legal nature should be directed to Ms. Wagner at (212) 637-3141. Questions of a technical nature should be directed to Elizabeth Butler, Remedial Project Manager, at (212) 637-4396.

Sincerely yours,

R. Basso

Ray Basso, Strategic Integration Manager
Emergency and Remedial Response Division

Enclosure

cc: Gordon C. Andrews, General Counsel

PARTIES RECEIVING EPA GENERAL NOTICE LETTER

David M. Cote, Chief Executive Officer
Honeywell International, Inc.
101 Columbia Road
Morristown, New Jersey 07962

President
Prentiss, Inc.
C.B. 2000
Floral Park, New York 11001

Mr. Ralph Izzo, President
Public Service Electric & Gas
80 Park Plaza
Newark, New Jersey 07102

Daryl D. Smith, President
Troy Chemical Corporation
8 Vreeland Road
P.O. Box 955
Florham Park, New Jersey 07932

TROY CHEMICAL COMPANY, INC.
ONE AVENUE L
NEWARK, ESSEX COUNTY, NJ
EPA ID # NJD002144517

GENERAL INFORMATION AND SITE HISTORY

Troy Chemical Company, Inc. is located at 1 Avenue L in a heavily industrialized section of Newark, Essex County. The company has manufactured specialty paint additives at this 6 acre facility since approximately 1956. Prior to 1956 the site was utilized by numerous industries including American Cyanamid/Calco, Heller and Merz, and Amalgamated Dyestuff and Chemicals for the manufacture of a variety of chemicals and dyes.

The site has been subdivided many times since the early 1900s making it difficult to assess exactly who previously owned/operated which portions of the present Troy site. However, review of Sanborn Fire Insurance Maps covering the time period between the early 1900s and 1951 revealed the current Troy site, along with the Albert Steel Drum/Prentiss Drug and Chemical site located directly north of Troy's facility, were actually part of one large operation. This facility extended from Wilson Avenue almost to Delancey Street in a north to south direction, and from Avenue L to the railroad tracks in a west to east direction. It is unknown exactly when the larger site was divided into its present day dimensions but it is believed the final subdivision occurred sometime in the early to mid-1950s.

According to the Sanborn Maps, Heller and Merz Company, a manufacturer of colors and dyes, operated here from 1908 to 1931. From 1931 to 1951 the maps indicate that Calco Chemical Company and American Cyanamid occupied the property. The dates provided in the Sanborn Maps are very rough estimates since these maps were only updated periodically. It is probable other industries also operated at the site between 1908 and 1951 but commenced and ceased operations between the periodic updates of the maps.

A deed search at the Essex County Hall of Records indicates the following ownership chronology: (note: due to the lack of records prior to 1951, accurately determining the exact owners is difficult)

Current owners -	Troy Chemical Company, Inc.
June 24, 1980 -	New Chemical Corporation purchased the property from the Troy Chemical Corporation. In actuality, New Chemical was formed to purchase the assets of Troy Chemical, and immediately after the acquisition changed its name to the Troy Chemical Corporation, Inc. (current owners). The name New Chemical Corp. was used to avoid confusion at the time of aquisition. (note: many of the principles of the former Troy chemical Corportation are involved with Troy Chemical Corp. Inc. and New Chemical in similar capacities).

November 5, 1960 -	Troy Chemical Corporation purchased the property from the Pulaski Skyway Realty Corporation. At this time a separate industry, the Wilson Refining Company, was leasing and operating out of Building 61.
February 20, 1951 -	The Pulaski Skyway Realty Corporation purchased the property from the Pulaski Skyway Realty Company.
December 28, 1945 - and August 7, 1946	The Pulaski Skyway Realty Company purchased portions of the property from American Cyanamid/Calco.
April 20, 1938 -	Calco purchased a portion of the property from Amalgamated Dyestuff and Chemical.
December 29, 1932 -	Calco purchased a portion of the property from Harry L. Huelsenbeck, sheriff of Essex County. This portion of the site was formerly owned by the Monarch Distributing Company and apparently auctioned off in a sheriff's sale by Mr. Huelsenbeck.
March 12, 1930 -	Calco purchased 28 tracts of land from the Heller and Merz Company.

Further searching through the deeds revealed much of this area was owned by private citizens prior to 1930.

Although land use in the immediate vicinity of the site is characterized by heavy industry, numerous large residential sections of Newark, Kearny and Harrison exist within a 3 mile radius of the site. The nearest residential area to the site lies approximately 0.5 mile to the north within the City of Newark. Additionally, demography for the area cannot be limited to the established populations. Extensive "transient" populations are continuously present at the Newark Airport and the New Jersey Turnpike and may be susceptible to sudden releases from the Troy facility. The Newark Airport is approximately 1 mile south of the site and the Turnpike is less than 2000 feet to the east.

SITE OPERATIONS OF CONCERN

Troy Chemical Company manufactures a variety of specialty chemicals used in the paint industry as preservatives, biocides, dryers, rheology agents (flow agents), surfactants and dispersants. Non-mercurial biocides are the company's major product, accounting for approximately 52% of Troy's total operations (based on 1987 percentages). The remainder of Troy's total operations are incorporated in the production of driers (19%), surfactants (12%), LLBA (6%), defoamers (4%), dispersants (3%), rheology agents (3%), catalysts (<1%) and anti-skinning agents (<1%). The company also formerly manufactured mercury based compounds which were used as preservatives and bacteriocides in paint. According to company officials, mercury related operations accounted for approximately 6% (based on 1986 production totals) of the company's total operations; however, the manufacture of these compounds ceased in February 1987. The company maintains the above referenced information concerning the production totals is confidential, and should remain confidential under statutes set forth in section

Production of the speciality chemicals occurs almost exclusively through batch mixing and blending operations. Due to the extensive number of compounds manufactured by the company and the limited knowledge of the majority of the manufacturing processes, only general process schemes for organic fungicides, metallic soaps (drying agents) and mercury compounds will be discussed in this report.

The production of Troysan Polyphase products, the tradename for Troy's organic fungicides, involves mixing monoethanolamine and paraformaldehyde in a reactor and then heating the mixture. The resulting product is filtered off and the filtrant is adjusted to the proper concentration. According to company officials, no waste is generated in this process. Spent filter paper from all manufacturing processes is reportedly shipped off site as hazardous; however, the fate of the filtrate is unknown.

Metallic soaps, including those containing zinc, lead, zirconium, cobalt, copper, magnesium and calcium are manufactured in Buildings 90 and 91. Each specific type of metallic soap is manufactured to a predetermined content of the particular metal. For instance, the metallic soap Troymax Lead 24% (tradename) would be a lead soap containing 24% lead.

The general process scheme for the production of the metallic soaps involves mixing an organic acid and a solvent in a reactor. The metal source (usually a metal oxide) is added and a reaction is accomplished through heating and agitation. The metal source, as well as the organic acid and solvent, varies for the production of each specific type of soap. Excess solvent/water is separated and used in the next batch for that particular soap. According to company officials, there is no waste generated during these processes.

The production of the mercury compounds appears to have been the most involved of all of Troy's manufacturign operations. Mercury was purchased in metallic form and converted to mercuric oxide. The mercuric oxide was the major precursor in the production of organic mercuric compounds such as phenylmercuric acetate, choromethoxypropyl mercuric acetate, phenyl mercuric sulfide and phenylmercuric oleates.

This first step in this process involved washing mercury metal to triple distilled purity by allowing the mercury to fall through a column containing an acid solution. This mercury washing generated approximately 2 to 3 gallons of acid solution every few months (note: the fate of this acid solution is unknown). The washed mercury metal was then reacted with concentrated nitric acid to form mercuric nitrate. The mercuric nitrate was reacted with sodium hydroxide and the resultant mercuric oxide removed by filtration. The filtrate from this process was one of the major sources of mercury bearing wastewater, accounting for approximately 700 gallons of wastewater per batch with an average of 10 batches per week. Spills, leaks and equipment washings from this operation were another source of mercury-bearing wastewater.

In the manufacture of the organic-mercuric compounds from the mercuric oxide, only the production of the phenyl mercuric sulfide resulted in wastewaters to be discharged (not recycled back into operation).

Of the four organic-mercuric compounds manufactured by the company, only described in any detail. This process involved the mixing of benzene, acetic acid and mercuric acid in a reactor. The resulting PMA was adjusted to the proper concentration by the addition of solvent. After the reaction was complete, the vessels were rinsed with benzene and the solution generated placed in drums for use in the next batch.

Reportedly all discharged mercury bearing wastewater, including that generated in the production of mercuric oxide and phenyl mercuric sulfide, entered a sulfide precipitation treatment system. This system should not be confused with the company's overall wastewater treatment system and therefore, to avoid confusion in the report, we will refer to the two systems separately as the mercury bearing wastwater treatment system and the overall plant wastewater treatment system.

Prior to 1965, all process wastewaters, including untreated mercury bearing wastewaters, were discharged to Pierson's Creek which roughly bisects the site north to south. From 1965 to 1976, the mercury bearing wastewaters were treated by sulfide precipitation prior to being discharged to Pierson's Creek; however, all other process wastewaters were still being discharged untreated into the creek. In 1976, the overall plant wastewater treatment system was installed, receiving both the effluent from the mercury bearing wastewater treatment system (prior to cessation of the mercury operation) and the wastewaters from all of the "non-mercury" processes.

The mercury-bearing wastewater treatment system consisted of two settling tanks (A and B), a reaction and precipitation tank, a plate and frame filter press and another settling tank. The mercury bearing wastewater was discharged to Settling Tank A and liquid was allowed to overflow to Settling Tank B where the pH was adjusted to approximately 9.0. The wastewater was apparently discharged to the neutralization tank where calcium sulfide and iron sulfate were added. After agitation, the wastes were filtered and the filtrate recycled until the mercury content was reduced sufficiently for discharge to the Passaic Valley Sewage Commission (PVSC). However, prior to discharge to the PVSC the wastewater was treated in the overall plant wastewater system. Filter cake remaining on the filter paper was heated to drive off the mercury. This heating probably occurred in the three on site muffle type furnaces used by the company to recover mercury from sludges and other solid materials. A discussion of the muffle furnaces will be included in the section on the air route. After the mercury was driven from the filter cake, the remaining material was disposed of in the on site dumpster. According to Mr. Milton Nowak, Vice President of Troy Chemical, the material disposed of in the dumpster consisted basically of clay and iron oxide; however, it is unknown if this material had been analyzed.

The overall plant wastewater treatment system received the wastes from the mercury bearing wastewater treatment system in addition to waste streams from other company processes. However, as was previously stated, the company reincorporates much of their cleaning solutions generated from washing the process equipment back into the next reaction for that particular process, thereby limiting the amount of wastewater generated. Herein lies a disparity between various reports as the company's IWMF worksheet states wastewaters entering the treatment system are "generated from the washing of reactors used during production process operations".

The wastewater from the washings and spills is collected in sumps located in the process building. From here the wastewater is discharged to a 10,000 gallon collection tank. An oil/solvent layer is allowed to form on the surface and is then discharged to a 5,000 gallon tank where it is stored until a large enough quantity is collected for offsite removal. According to company officials, it takes approximately 1.5 to 2 years for a large enough quantity to accumulate to make it economically feasible for removal. This waste is considered hazardous.

The "water" remaining in the 10,000 gallon collection tank is then pumped to a second 10,000 gallon tank where neutralization and precipitation occur. The wastewater is then filtered and the filtrate is discharged to the Passaic Valley Sewage Commission (PVSC) under provisions provided in a sewage connection permit (#20403290). Troy Chemical continuously monitors the effluent discharge to the PVSC for LEL and pH. The effulent is also monitored quarterly for Biological Oxygen Demand (BOD), Total Suspended Solids (TSS) and petroleum hydrocarbons (PHCs). The effluent was formerly monitored for mercury triweekly prior to the cessation of the mercury processes.

The fate of the precipitate, filtrant and spent filter material (cloth) generated during the filtration and precipitation stages of the overall wastewater treatment system is unknown. According to Ed Capasso, Environmental Manager for Troy, the filter material consists of a cloth mesh; however, he believes most of the solid passes through. Also of interest is the fact that the wastewater remaining after the oil/solvent layer is not analyzed for volatile organics because it is not believed to be necessary. However, this does not take into consideration the possible presence of substances such as TCE and tetrachloroethylene which are more dense than water and would sink rather than float.

Another source of confusion concerning the Troy facility is the determination of the company's RCRA status. In November 1980, the company submitted a Part A RCRA application for storage of hazardous wastes in containers and tanks. The company was subsequently listed as a RCRA TSD facility. However, when the EPA requested submission of the Part B application in 1982, the company claimed they "need not store hazardous wastes on site for more than 90 days and accordingly hereby withdraws its application for a RCRA permit". Troy was delisted to generator only status in October 1983 by the USEPA and, after considerable controversy, by the NJDEP in August 1984. The two separate dates for delisting occurred as a result of variance in the state and federal regulations concerning classificastion of TSD facilities. Under New Jersey regulations, a facility which stores hazardous wastes in tanks for a period of time is considered a TSD whereas, under federal regulations, tank storage of hazardous waste must occur for more than 90 days for a facility to be classified as a TSD.

The company's RCRA status becomes even more confusing in light of the fact that hazardous waste (the oil/solvent layer from the wastewater treatment plant) is currently stored on site in tanks for a period exceeding 90 days. Based on this information, the company would be considered a TSD under both state and federal regulations. However, under criteria set forth in NJAC 7:14A-4.2(a), the company avoided TSD classification by being considered a Industrial Waste Management Facility (IWMF) under Division of wastewater treatment facility receiving an influent wastewater which is a hazardous waste and generating a residue (the oil/solvent layer) which is also considered hazardous. Since the hazardous waste storage tank is an integral part of the wastewater treatment system, the tank falls under IWMF regulations. A "gray" area exists between IWMF and RCRA classification in that a company can be considered a TSD as well as an IWMF if the residue generated is stored in containers for longer than 90 days. However, the same does not apply for tank storage. Since containers and tanks would both be considered RCRA regulated units under normal circumstances, the loopholes which exist in the current regulations do not appear to be justifiable. The major concern with the company being classified as an IWMF only is that no secondary containment is required around the IWMF hazardous waste units.

As was previously stated, the oil/solvent layer from the wastewater treatment process is collected in a tank until enough has been generated to make it economically feasible to transport it off site. Solvents Recovery Service (SRS) of Linden, New Jersey formerly received the majority of Troy's oil/solvent wastes. According to Mr. Cappasso, the last shipment of the hazardous oil/solvent material occurred sometime in 1986. Mr. Capasso stated another shipment should be made sometime in 1988.

Other hazardous waste (from a RCRA standpoint) generated at the facility included spent sorbent booms from Pierson's Creek as well as filtrate and spent filter paper from the manufacturing processes. It is believed these wastes are stored in drums; however, drum storage reportedly occurs for less than 90 days. The filtrate and filter paper are assumed to be hazardous and have been shipped by AETC to an incinerator in North Carolina operated by Stablex. The sorbent booms which were placed in Piersons Creek to contain spills will be discussed in the section on surface water.

A review of aerial photographs at the NJDEP, Office of Environmental Analysis revealed numerous suspicious areas which also warrant further investigation. Areas of concern from the photographs reviewed will be discussed in turn.

Photographs covering the period 1934 to 1940 (photos dated November 1934, April 6, 1940 and April 28, 1940) revealed that most of the current Troy site was undeveloped; however, a few buildings were present on the eastern side of Pierson's Creek. These buildings were probably part of the American Cyanamid/Calco site previously referenced. It appears that landfilling operations had begun throughout much of the remainder of the current Troy site, especially on the western side of Pierson's Creek. In the 1954 photo, what appears to be drums are located in the landfill area. It is unknown if the landfilling was related to the American Cyanamid/Calco operations.

Photographs dated April 7, 1951 and December 5, 1953 revealed a more defined landfill area. An access road to the landfill(which is outlined in white) is visible in the 1951 photograph. Buildings and a few above ground tanks are present on the eastern side of the creek. The 1953 photo reveals a suspicious white area in the approximate center of the landfill and possible stained ground near what would be the northern border of the current Troy site.

The most revealing of all of the photographs was that taken on April 20, 1961. More buildings and aboveground tanks are present on the eastern side of Pierson's Creek. Although it cannot be substantiated by the aerial photographs only, it appears hundreds of drums were stacked for burial in the southwestern quadrant of the landfill area. It is difficult to assess if this suspicious area would actually be on the present-day Troy site as the landfill area appears to have extended well beyond (in a westerly direction) the present day Avenue L.

The March 25, 1972 aerial photograph revealed the majority of the facilities are still located on the eastern side of Pierson's Creek although aboveground tanks are also present on the western side of the creek. Most, if not all of the site is still unpaved.

Photographs from August 6, 1978 revealed the company's operations had grown immensely. Above ground tanks and thousands of drums are evident throughout the site. Most of the site still appears to be easily accessible.

The most recent photographs reviewed were taken on March 23, 1986. Most of the site appears to be unpaved and resembles its present day state; however, one suspicious area was noted in the southwestern portion of the property.

GROUNDWATER ROUTE

The Troy Chemical Company site lies within the Peidment physiographic province of the Appalachian Highlands physiographic division. Geology in the area is characterized by formations of Recent, Pleistocene and Triassic Age deposits.

Each of these units as they relate to the site will be discussed in turn. General information pertaining to geology in the vicinity of the site was obtained from the USGS Special Report #10 entitled, "Preliminary Report on the Geology and Groundwater Supply of the Newark, New Jersey Area" and Special Report #28 entitled "Groundwater Resources of Essex County, New Jersey". More site specific data was obtained from a hydrogeological study performed for Troy Chemical by Wehran Engineering in 1981. This study included installation and monitoring of six onsite monitor wells.

Since the two streams which transverse the site are actually man-made drainage ditches, unconsolidated recent deposits, originating from stream deposition are not an integral part of the site geology.

According to boring logs developed during installation of the onsite monitor wells, the uppermost "geologic" unit at the site would consist of fill material ranging from 6 to 10 feet in depth. The presence of fill is consistent with the information obtained during review of the aerial photographs. It is interesting to note that Boring Log 3A indicates a huge void was encountered at a depth of 6.2 feet. The location of Boring 3A would very roughly approximate the area of possible drum burial observed in the 1961 aerial photograph. According to the boring logs, the fill material appears to consist of concrete, bricks, cinders, wood and boulders as well as sand and gravel. Monitor Well 3A is screened exclusively in this unit.

The first naturally occurring geologic unit encountered would be the unconsolidated sediments of Pleistocene Age. The Pleistocene sediments could be divided into two general categories, stratified or unstratified drift. These sediments consist basically of clay, silt, sand, gravel and boulders. The deposits in the Newark area are mostly considered unstratified drift deposits and are therefore not heavily utilized as a groundwater source since sufficient quantities of water can only be obtained from deposits in the stratified drift. For the purpose of this report, the lithologic units described in the Wehran Engineering boring logs occurring between the fill material and the residual bedrock encountered in Boring 1 will be considered as the Pleistocene Deposits. According to the boring logs these include lacustrine as well as glacial till deposits. Only one boring (Boring 1) was progressed into the Brunswick Formation, therefore the thickness of the Pleistocene deposits at the site can only be assessed from this one boring (assuming the Pleistocene deposits are the entire unit between the fill and the Brunswick Formation). The depth of this unit, as determined from Boring 1, is approximately 65 feet thick. According to the boring logs, no extensive aquifer system (sand or gravel) is present at the site, however most of the units within the Pleistocene deposits, especially within Borings 2 and 3, were reported to be saturated, possibly indicating that this system does not serve as an adequate aquitard and is capable of groundwater storage and transmittal. Therefore, vertical and horizontal migration of contamination is possible. All of the wells, with the exception of Monitor Well 3A, are at least partially screened within the Pleistocene deposits. Groundwater flow in these deposits appears to be in a south-southeast direction.

The last unit encountered is the Brunswick Formation, which consists of consolidated shales in the vicinity of the site. Although the primary porosity of the shale itself is extremely low and inadequate for storage and transmittal of groundwater, secondary porosity resulting from cracks and fractures provides ample space for groundwater storage. Numerous industrial and cooling water wells in the vicinity of the site draw from the Brunswick Formation. Review of well records at the NJDEP/Division of Water Resources/Bureau of Water Allocation also indicated a few wells in the Newark area utilize the Brunswick Formation for domestic purposes; however, officials of the Newark City Water Department claim that everyone in Newark is connected to the city water supply. This water is obtained from the Pequannock and Wanaque water sheds. Only Boring 1 was progressed into the Brunswick Formation; however, the well screen was ended in the Pleistocene deposits. Due to the nature of the Brunswick Formation, with groundwater transmittal occurring through cracks and fractures, no definitive grounwater flow direction can be ascertained.

Contamination of the Brunswick Formation resulting from site activities is possible due to the leaky nature of the Pleistocene deposits and the fact that the Brunswick Formation probably receives most of its recharge from the overlying units.

The six Monitor Wells were sampled on four occasions between August 1981 and May 1982 by the Wehran Engineering Company. Split samples were obtained by NJDEP on two of these occasions. A summary of the available groundwater data is included in Tables 1 through 6.

The wells were initially sampled by Wehran Engineering on August 25, 1981 detected in all six wells; however, only the concentration in Monitor Well 1A (9.3 ppm) exceeded the Groundwater Quality Criteria Guidelines of 5 ppm. Mercury was detected in five of the wells with the concentrations above the Groundwater Quality Guidlelines of 2 ppb in each of these wells. Concentrations of mercury ranged from 85 ppb in Monitor Well 2 to 22.96 ppm in Monitor Well 2A.

Both the NJDEP and Wehran collected samples from the six wells on November 11, 1987 (see tables 2 and 5). Samples collected by the NJDEP were analyzed for mercury, copper, lead, zinc, pesticides/PCBs, chloride and COD. The Wehran samples were analyzed for purgable organics, pesticides/PCBs, COD, chloride, mercury, copper, lead and zinc. Analysis of the Wehran samples again revealed mercury contamination above the Groundwater Quality Guidelines in the same five wells as during the August 25, 1981 sampling episode. In addition, the levels of copper in Monitor Wells 1A, 2A, 3; lead in 2, 2A and 3; benzene in 1A, 2 and 3A; chlorobenzene in 1A; tetrachloroethylene in well 3A; 1,1,1-trichloroethane in 3A; and TCE in 2A and 3A were above the Groundwater Quality Criteria. Toluene was also detected in low concentrations in all six wells. Extremely high concentrations of chlorides were also detected in all six wells, but this probably attributable to salt water infiltration. The NJDEP samples also revealed concentrations of mercury above the Groundwater Quality Criteria in every well with the exception of Monitor Well 2. The metals fraction for the Monitor Well 2 sample was not properly preserved and therefore not analyzed. It should be noted that although the mercury concentrations were above the Groundwater Quality Criteria, they were at levels much lower than those detected in the Wehran samples. The discrepancies in the concentrations may be a result of differing sampling and/or analytical protocols. Also, since it cannot be ascertained whether the samples were actually split properly between the two sampling groups (DEP and Wehran), it is possible the aliquots collected by each group had varying concentrations of contaminants. Of special interest in the NJDEP samples was the presence of 7.5 and 6.5 ppb of Aroclor-1254 in Monitor Wells 2 and 2A, respectively. Since Aroclors do not readily migrate through the soil column and into groundwater, the source of the Aroclor contamination in these wells may be the result of "tainted" fill or the actual disposal and burial of Aroclor wastes. Another possibility is that migration was facilited by the presence of solvents which acted as carriers. The wells were again sampled by Wehran Engineering on May 14, 1982 (see Table 3). The samples were analyzed for mercury only, with the concentrations in all six wells above the Groundwater Quality Criteria. The highest concentration, at 12.5 ppm was again detected in Monitor Well 2A.

On May 27, 1982, the wells were sampled again by NJDEP and Wehran (see Tables 4 and 6). The NJDEP samples were analyzed for a variety of parameters including arsenic, cadmium, lead, mercury, hexavalent chromium, cyanide, chloride, COD and volatile organics. The Wehran samples were analyzed for mercury only. The concentrations of mercury in all six wells for both the NJDEP and Wehran samples were above the Groundwater Quality Criteria, with the concentrations detected in the Wehran samples again well above the concentrations in the NJDEP samples. Here again the differences in concentration may be attributable to varying sampling and/or analytical procedures. Other analytes surpassing the Groundwater Quality Guidelines included arsenic in Wells 1, 1A and 3A; lead in 2 and 3; cyanide in 2A and benzene in 1A, 2A and 3A; and chlorobenzene in 1A and 2A. Numerous aromatic compounds were also detected in many of the samples.

On November 17, 1989, NJDEP Bureau of Planning and Assessment (BPA) conducted a Site Inspection (SI) which included the sampling of Monitor Wells 2 and 2A to be analyzed for the Target Compound List (TCL) plus 30 peaks and PHCs. Analysis of Monitor Well 2 showed levels of cadmium (18 ppb), chromium (241 ppb), lead (1,140 ppb), PHCs (7,600 ppb), and benzene (2,600 ppb) above Groundwater Quality Criteria Guidlines as well as low levels of other organic compounds. Analysis of the deeper well (Monitor Well 2A) revealed levels of chromium (118 ppb), lead (515 ppb), mercury (4.96 ppb), benzene (2,200 ppb), and toluene (18 ppb) over clean-up levels as well as low levels of other organic compounds. See Table 11 for complete results.

Monitor Wells 1 and 1A were not sampled due to the fact that they had been destroyed and covered over with macadam. Monitor Wells 3 and 3A were not sampled because the covers could not be removed without removing part of the well casing.

It is important to note that many of the contaminants detected including mercury, lead, copper, zinc and benzene are highly utilized in many of the company processes possibly implicating Troy Chemical as at least a partial contributor to groundwater contamination in the area. Also noteworthy is the presence of contamination in both the shallow and deep monitor wells indicating vertical migration of the contaminants. The extremely high concentrations of mercury consistently detected in Monitor Wll 2A, especially in the Wehran samples, may represent evidence of a small pocket (plume) of contamination in the vicinity of this well.

SURFACE WATER ROUTE

Two small drainage ditches exist within the Troy Chemical site. The two ditches converge near the approximate southern border of the Troy site, eventually discharging to Newark Bay. Tank farms, process buildings and storage areas line both sides of the westernmost drainage ditch known as Pierson's Creek which bisects the site north to south. According to reports, Pierson's Creek was originally part of a private drainage system which extended to a stream known as Dead Creek. This system was constructed sometime in the mid 1800s when this area of Newark was first being developed. Although the current origin of Pierson's Creek is unknown (Dead Creek cannot be located on present day maps), it appears to run underground upstream of the Troy Site, at least partially through the Albert Steel Drum/Prentiss Drug Site, finally surfacing at a point approximately 50 yards north of Troy's property. As the creek enters the Troy site, the drainage ditch turns into a concrete flume. The City of Newark installed the flume in 1956; however, it is not known if it is continuous until the creek terminates at Newark Bay. In June 1977, the company installed a containment wall along the flume to prevent the migration of spilled/leaking materials into Pierson's Creek; however, numerous inspections revealed cracks and holes in the wall which permitted materials to discharge directly into the creek.

The easternmost creek roughly borders the eastern edge of the Troy site and is labeled as a tributary to Pierson's Creek on various reports. This creek was reportedly part of Newark's storm drainage system as early as 1910. The origin of this creek is unknown. This creek is also concrete lined.

As previously stated, all of Troy's process wastewaters (including mercury bearing wastewaters) had been discharged untreated into Pierson's Creek from the mid-1950s to 1965. From approximately 1965 to 1976, mercury bearing wastewaters were treated by sufide precipitation prior to being discharged to the creek; however, all other process wastewaters continued to be discharged untreated. Finally in 1976, the overall plant wastewater treatment system was installed resulting in the treatment of all wastewater before discharge. The fate of precipitate generated from the sulfide precipitation process (operating from 1965 to approximately 1987) is unknown.

In July 1977, Troy applied for a NJPDES permit to discharge noncontact cooling water, boiler blowdown and condensates into Pierson's Creek. This permit (#0031453) was effective from May 31, 1978 to September 30, 1980. Six discharges, designated 001 to 006, where included in the initial permit. The following describes the sources of the discharges:

001 -	non contact cooling water from reactor vessels and blowdown from cooling towers.
002-003 -	boiler blowdown - only active in winter.
004-006 -	steam condensate from steam traps on heaters and other steam lines.

In March 1980, Troy submitted a renewal application for their NJPDES permit, however as a result of deficiencies in the renewal application due in part to the transfer of the company's assets, which occurred at this time, the NJDEP refused to recertify Troy's NJPDES permit. Although the permit was not renewed until August 1985, the company continued to discharge to Pierson's Creek. According to Michael Russo of the NJDEP/Division of Water Resources/Bureau of Industrial Waste Management, a company would be allowed to continue discharging under the previous permit limitations as long as the revised permit renewal application was submitted in a timely manner, which apparently occurred in this case. Prior to obtaining the renewed permit, Troy discontinued the discharges from Discharges 002 to 006. Under provisions of the renewed permit, which is valid until September 30, 1990, the company is required to monitor Discharge 001 on a monthly basis for flow, pH, temperature, TSS, COD and oil and grease. In addition, this discharge is monitored quarterly for benzene, mercury, zirconium, cobalt and iodine. Review of the Discharge Monitoring Reports (DMRs) for the period covering January 1986 to June 1988 revealed the company has had only one excursion of any of the permit limitations. The excursion occurred in April 1988 when the Total Suspended Solids limitation of 50 ppm was exceeded by a TSS of 70 ppm. It should also be noted, that 20 ppb of benzene was reported in the January 1988 DMR.

Although the DMRs, especially those from 1986 to the present, show commendable NJPDES compliance, non NJPDES regulated sampling (either sampling conducted prior to the company obtaining their NJPDES permit or samples of non NJPDES regulated discharges) reveal gross contamination of Pierson's Creek and its sediment. Due to the extensive sampling of discharges to the creek, the creek sediment and the creek itself, each individual sample will not be discussed in this report. However, a brief description of significant data collected will follow.

On August 18, 1977, the NJDEP/Division of Water Resources collected samples of discharges to Pierson's Creek, as well as samples of the creek itself. The sources of the discharges included an onsite septic tank, cooling water from the Mercury Distillant Plant, the fungicide plant and the boiler room. The parameters selected for each sample were specific to the discharge source location. For example, the septic tank discharge was analyzed for parameters usually associated with sewage such as nitrates, nitrites, ammonia, chloride and various indicator parameters. The indicator parameters include, but are not limited to, color, pH, total solids and COD. (Note: these indicator parameters were also analyzed in other samples but for the remainder of the report will be referenced only as indicator parameters). Two water samples, one upstream and one downstream of the septic tank, were collected from Pierson's Creek and analyzed for the same parameters as the septic tank discharge samples. Of interest in the two stream samples was the increase in ammonia and nitrites in the downstream sample. The highest level of these contaminants was detected in the discharge sample itself with the level in the downstream sample approximately one half the concentration detected in the discharge sample:

	DISCHARGE SAMPLE	DOWNSTREAM SAMPLE
Ammonia	26.1 ppm	16.4 ppm
Nitrite	0.010 ppm	0.0006 ppm

The results of these samples indicate that the company's septic system was discharging sewage into Pierson's Creek. Dye testing of the company's toilet facilities during a previous NJDEP inspection revealed the location of the septic tank discharge.

The sample of the cooling water discharge from the Mercury Distillant Plant was analyzed for chromium (total and hexavalent), copper, lead, zinc, mercury and indicator parameters. High levels of mercury (42.2 ppb) as well as low concentrations of lead (0.001 ppm), copper (0.020 ppm), total chromium (0.002 ppm) and zinc (0.525 ppm) were detected in this sample.

The Fungicide Plant sample was analyzed for mercury, lead, zinc, chromium (hexavalent and total), calcium, iodine, pesticides and indicator parameters. In addition to 39 ppb of mercury, significant concentrations of iodine (4.0 ppm) and ronnel (8.7 ppm), an insecticide, were detected in this sample. Low concentrations of zinc, lead and total chromium were also detected. The pH of this sample was reported to be 10.3.

Stream and discharge samples were again collected by the NJDEP on September 1, 1977. Two stream samples were collected from Pierson's Creek, one upstream sample near the northern portion of site just as the stream enters the Troy site and one onsite sample from near the Mercury Reclaiming Plant. Both samples were analyzed for mercury, lead, zinc, chromium (hexavalent and total in the downstream sample, total only in the upstream), sulfate and indicator parameters. Of greatest significance in these two samples was a greater than five fold increase in mercury concentration in the downstream sample indicating a discharge from an onsite source was contributing to contamination of the creek.

Two discharge samples were also collected on September 1, 1977. Sources of these samples consisted of overflows from the wooden cooling water tank and the boiler room. Both of these samples were analyzed for similar parameters including mercury, lead, zinc, sulfate, total chromium, calcium and indicator parameters. In addition, the sample from the wooden cooling tower was analyzed for iron. Mercury, zinc, calcium and sulfate were detected in low concentrations in both of the samples. Iron and total chromium were also detected in the wooden cooling tower and boiler room overflow samples, respectively.

Mercury and zinc were detected in a sample of cooling water discharge from the Mercury Distillant Plant collected by the NJDEP on December 8, 1977. Besides zinc and mercury this sample was also analyzed for arsenic and indicator parameters.

Nine samples, including four surface water and five sediment samples, were collected along and near Pierson's Creek during an inspection by the USEPA on June 6, 1979. All of the samples were analyzed for mercury content only. Two of the water samples were collected directly from Pierson's Creek, one upstream and one downstream of the Troy facility. A significant increase in mercury in the downstream water sample (56 ppb versus 0.5 ppb) indicates the Troy facility is the source of the largest portion of the contamination. It should be noted that the concentration of mercury detected in the sediment samples decreased in the downstream versus upstream sample. This may be due to migration of insoluble forms of mercury from the upgradient Albert Steel Drum/Prentiss Drug site which also has documented mercury contamination. However, since Pierson's Creek can be considered tidal, contaminated sediment can also be carried short distances upstream during tidal stages. This effect (higher concentrations in upstream versus downstream samples) would not be apparent in water samples unless sampling occurred as the tide was coming in.

As a result of the information obtained during the June 6, 1979 inspection, the USEPA requested a search warrant to investigate the site under provisions provided in section 1318(a) (B) of the Clean Water Act. In the request for the warrant, the USEPA indicated the company was discharging mercury in possible violation of their NJPDES permit. The warrant was subsequently issued by the U. S. District Court for the New Jersey District with an investigation being conducted by the USEPA on July 12, 1979. During the investigation, water and sediment samples were collected from Pierson's Creek at locations 5 and 100 feet upstream of the Troy Site, 100 and 250 yards downstream and at two locations within the site. Of the four samples collected on site (two water and two sediment), two samples (one water and one sediment) were collected approximately 50 feet upstream of the southern edge of the plant near Dicharge 001, and the two other samples (one water and one sediment) were collected near the mercuric oxide manufacturing area. All of the water samples were analyzed for heavy metals and Total Organic Carbon (TOC). The sediment samples were analyzed for mercury only. Four additional water samples were collected from Pierson's Creek and analyzed for volatile organics. Of the four additional samples, one was collected approximately 5 feet upstream of the Troy Site, one within the site, downstream of all the manufacturing processes and two at locations 100 and 250 yards downstream of the Troy property. A summary of the data is included in Table 7.

The majority of volatile organics detected in the downstream water samples were at higher concentrations than in the upstream (background) sample, indicating most of the contamination is emanating from the Troy site. Also of interest are the concentrations of mercury in the sediment samples, especially those collected from within the Troy site boundary. A substantial increase in mercury concentration in Pierson's Creek is evident in the samples collected from onsite sources versus samples collected from upgradient offsite sources. Although the mercury concentrations detected in the upgradient offsite samples should be considered significant (140 ppm, 100 feet upstream and 191 ppm, 5 feet upstream), the concentrations in the onsite samples (22,400 ppm and 11,600 ppm) are indicative of continuous discharges and/or spills of insoluble forms of mercury over several decades. Also of interest is the increase of mercury concentration in the downstream (3,120 ppm, 100 yards downstream and 244 ppm, 250 yards downstream) versus the upgradient offsite samples (see above).This further substantiates that the company's activities have seriously impacted the quality of Pierson's Creek. In addition to the sediment samples from Pierson's Creek, one sediment sample was also collected from the easternmost creek. Mercury was detected at 83,200 ppm in this sample. ✓ ✓

The NJDEP performed additional sampling of the creek and discharges to such on August 2, 1979. A total of eleven samples were collected including seven discharge samples, two stream samples from Pierson's Creek and two sediment samples from Pierson's Creek. Apparently, one of the discharge samples actually discharged to the sanitary sewer, and therefore will not collected from the designated NJPDES Discharges 001, 005 and 006. The sample from Discharge 001, which was analyzed for volatile organics, mercury, arsenic, COD, and oil and grease, contained low concentrations of mercury (11 ppb), oil and grease (1.6 ppm) and COD (19 ppm).

Discharge 005 was analyzed for mercury and COD only, with 45 ppb of mercury and 12 ppm COD being detected. Similar concentrations of mercury (51 ppb) and COD (8 ppm) were detected in the Discharge 006 sample which was analyzed for volatile organics in addition to mercury and COD. Although the limitations for the six discharges in the initial NJPDES permit (issued in May 1978) are unknown, the concentrations detected in these samples were well below the current NJPDES limitation for Discharge 001. It should be noted however, that no mercury limitation has been established. One of the other discharges sampled on August 2, 1979 reportedly originated from the oil/water separator influent which discharges to Pierson's Creek (the oil/water separator was apparently located within Pierson's Creek).

This sample was analyzed for volatile organics and oil and grease. Significant quantities of benzene (726 ppb), tetrachloroethylene (500 ppb), and 1,2-dichloroethane (7250 ppb) were detected in this sample. A sample of the intake from Pierson's Creek leading to the oil/water separator also revealed the presence of benzene, tetrachloroethylene and 1,2-dichloroethylene, but at much lower concentrations than in the oil/water separator influent sample entering Pierson's Creek. The last discharge sample collected originated from the onsite locker room and was analyzed for parameters associated with sewage. Extremely high coliform counts in this sample indicated untreated sewage was being discharged directly into the creek.

Two water samples were collected from the creek itself, one from a location 5 feet upstream of the northern property line and one directly downstream of the southern property line. The upstream sample was analyzed for oil and grease, total chromium, arsenic, mercury and volatile organics; the downstream sample for phenols, oil and grease, total chromium, arsenic, volatile organics, mercury and pesticides.

A comparison of the concentrations of mercury, benzene, and arsenic detected in the two samples revealed a very slight increase in the downstream sample for each analyte, again indicating the company was contributing to surface water contamination. Phenols (102 ppb) and diazinon (1.62 ppb) were also detected in the downstream sample. Tetrachloroethylene, 1,2-dichloroethane, toluene and xylenes were detected in the upstream sample but not in the downstream sample, leading to the conclusion that the Troy Chemical Company is not the sole contributor to the contamination of Pierson's Creek. Sediment samples were also collected at upstream (10 feet north of the northern property line) and downstream (immediately inside the southern site boundary) locations. Both samples were analyzed for volatile organics, mercury, arsenic and total chromium. Although the concentration of mercury was lower in the downstream sample, 4.3 ppm versus 4.6 ppm in the upstream sample, the concentrations of arsenic and chromium were approximately four and ten times greater respectively, in the downstream versus upstream samples. Also of interest were the concentrations of chloroform (>50 ppm), 1,2-dichloroethane (7.815 ppm) and benzene (12.5 ppm) in the downstream sample. No volatile organics were detected in the upstream sample. A point worthy of reiteration is are (or have been) heavily utilized in the company's processes.

On April 28, 1980, six discharge samples and four soil samples were collected by the NJDEP. The soil samples will be discussed in the section concerning soils. Two of the discharge samples were collected from stormwater discharges to the easternmost drainage ditch (the tributary to Pierson's Creek) and were to be analyzed for mercury, copper, lead, arsenic and zinc. However, due to insufficient sample quantities, only mercury analysis was performed on one of the samples; the arsenic analysis was deleted on the other sample. In one of the samples a mercury concentration of greater than 3 ppm was reported. Mercury droplets were reportedly only as further substantiation of the company's continuing contribution to contamination of Pierson's Creek, but also as evidence that secondary containment at the site is inadequate to prevent spills and leaks from migrating to the creek. Based on these results, it could also be concluded that spills are not contained and removed promptly creating numerous "non-point source discharges" which ultimately permit the contaminants to migrate to the creek via stormwater runoff, overflows, etc.

Wehran Engineering collected water and sediment samples from Pierson's Creek in August of 1981 (exact date unknown). Three sediment samples identified as Upstream #1, Midstream #2 and Downstream #3 were analyzed for total solids, volatile solids, COD and mercury. The supernatant from the sediment samples was analyzed for total organic carbon and mercury. Review of the data for sediment and supernatant samples revealed elevated levels of mercury in the upstream samples relative to the downstream samples. However, all three samples were collected well within the Troy site, therefore, the upgradient sample cannot be considered truly indicative of the contamination being contributed by offsite sources. It should also be noted that many of the mercury process areas were located along Pierson's Creek near the Upstream #1 sample location. Also of interest in the sediment samples was the progressive increase in the concentration of volatile solids and COD in the midstream and downstream samples revealing the presence of oxygen demanding constituents (possibly the volatile solids) in the middle and lower sections of the creek. Two water samples were also collected from the creek, one just as the creek enters the site (background) and one as the creek leaves the site. The samples were analyzed for mercury and zinc with elevated levels of both contaminants present in the downstream sample. Here again, the increase in contamination in the downstream sample revealed soluble forms of zinc and mercury are continuously being discharged to the creek from the Troy site.

On May 1, 1985, one sample was collected at NJPDES Discharge 001 by the NJDEP. The sample was analyzed for indicator parameters including chloride and COD. A field pH measurement using pH paper was also taken, with the reported value of 5.0 being below the NJPDES permit limitation of 6.0 standard units. Also, the level of COD (220 ppm) exceeded the NJPDES permit limitation of 50 ppm. The level of COD was estimated, however, since the sample was improperly preserved.

During the November 17, 1989 NJDEP, EPA Site Inspection, five surface water and seven sediment samples were collected and analyzed for the TCL plus 30 peaks. Surface Water/Sediments 1 through 4 were collected in Pierson's Creek with 1 being slightly upgradient of the facility and 2,3 and 4 located progressively downgradient.

The following contaminants were detected in Surface Water (SW)-1: benzene (10 ppb), lead (103 ppb), mercury (10.8 ppb) and PHCs (5,300 ppb). Analysis of SW-2 revealed detectable levels of volatile and semi-volatile organic compounds as well as elevated levels of lead (105 ppb), mercury (8.2 ppb) and PHCs (1,400 ppb). Detectable levels of volatile and semi-volatile organic compounds were found in SW-3 as well as elevated levels of 1,1,1-trichoroethane (210 ppb), trichoroethene (100 ppb), benzene (70 ppb), tetrachloroethene (60 ppb), lead (194 ppb), mercury (7.5 ppb) and PHCs (1,700 ppb). Analysis of SW-4 revealed detectable levels of volatile and semi-volatile organic compounds along with lead (263 ppb), mercury (66 ppb) and PHCs (7,400 ppb). SW-5, which was collected from a storm drain in the center of the current operational portion of the site, showed elevated levels of methylene chloride (460 ppb), lead (230 ppb) and PHCs (28,000 ppb).

While the surface water samples show a pattern of slightly elevated levels of organics, metals and PHCs from upstream to downstream samples, results of the concurrent sediment sampling are much more indicative of long-term discharges.

Progressively increasing levels of some organic and inorganic substances were found in Sediments-1 through 3 with Sediment-4 exhibiting lower values than Sediments-2 and 3. Of significance to this investigation is the pattern of increasing volatile organic, copper, lead and mercury concentrations. Table 8 represents upstream to downstream concentrations in Pierson's Creek sediment. See Table 11 for complete results.

Additionally, 4,4'-DDD, cadmium, chromium and zinc were detected in significant amounts in these samples; however, the higher upstream concentrations may be indicative of contaminants migrating from offsite sources.

Sediments-5, 6 and 7 were collected in the tributary to the east of the site, with Sediment-5 located upstream, Sediment-6 midstream and Sediment-7 downstream. As with Sediments-1,2 and 3, these samples indicate a pattern of increasing contamination from upstream to downstream locations. Table 9 summarizes the significant results.

The numerous samples which have been collected by the NJDEP, the USEPA and Wehran Engineering indicate that both permitted and unpermitted discharges by the company have had a detrimental impact on surface water quality in Pierson's Creek and its tributary. Although most of the samples collected were from continuous or common sources, another source of contamination from the company's activities, direct spill discharges, should also be considered. Historically, spills, leaks and poor housekeeping have contributed to contamination of the surface water by migrating to the creeks via storm water runoff, overflows, etc. Since the runoff, overflows, etc. would actually dilute the concentration of contaminants present, these discharges, although significant, may not be as deleterious to the creek as the direct spill discharges of pure product and/or wastes. Review of available information has revealed at least three "minor" spills of various substances including naptha, mineral spirits and sewage have occurred at the site since February 1987. These spills were reportedly contained and the spilled materials removed before any of the materials migrated off site. It is unknown if any unreported spills have occurred

Prior to 1987, however, direct spill discharges to Pierson's Creek apparently were commonplace. Many of these spills were not reported to the NJDEP by the company, as required in the Spill Act, but rather from complaints or "tips."

One such spill incident occurred in January of 1984 with the NJDEP being notified of the spill by the New Jersey Division of Criminal Justice. Samples collected by Division of Criminal Justice personnel revealed the creek upgradient of the site was clear, while downgradient of the site a brown and green liquid covered the surface of the stream. Field testing indicated the brown liquid was flammable. The exact source of the spill could not be determined by Marc Gruslovic of the NJDEP who responded to the spill, however the source was believed to be from near or within Building 91. Building 91 is currently a process building and probably served a similar function at the time of the spill. It is unknown if the aforementioned samples were ever analyzed. Troy Chemical contracted Clean Venture to contain and remove the spill material. The company claimed the green material observed was a dye, formerly manufactured by American Cyanamid when they operated at the site, which emanates from the ground whenever it rains.

A series of spills had also occurred in the fall of 1978 and the winter of 1979. The succession of events pertaining to these spills were reported by Ed Faille of the NJDEP. These events as they pertain to discharges to Pierson's Creek will be discussed in the following paragraphs. Further information concerning Mr. Faille's inspections will be discussed in the Other Considerations section under the heading "Unstable Containment of Wastes."

The first spill was inadvertently discovered by Mr. Faille on October 12, 1978 while inspecting the adjacent Albert Steel Drum site. Mr. Faille reported that oil was present in Pierson's Creek within the Troy site boundry. Upon further investigation of the Troy facility, numerous point source and non-point source discharges were discovered entering Pierson's Creek. The point source discharges included, "a pump that was leaking around the packing, discharging the waste materials into the stream", and a sump pump within the containment area for a tank whose contents were reported to be "metallic dryers and metallic naphthalene". The non-point source discharges included substances leaching into the creek from varoius onsite locations. The exact source of the oil observed by Mr. Faille was not reported, however, officials of Troy Chemical claimed that it originated from upstream sources. Several samples were colected during the inspection but apparently were never analyzed.

On October 19. 1978, Mr. Faille reinspected the site and observed numerous environmental problems including a white substance in the stream sediment. Several samples were collected but apparently were never analyzed.

Mr. Faille again inspected the site on October 26, 1978. During the inspection, it was observed that many of the discharges had been discontinued and a collection box was installed to prevent the leachate from discharging directly to the creek. In addition, the white sediment was removed from the creek and a boom was placed in the creek near the downstream property boundary. An inspection on November 1, 1978 revealed the collection systems were working effectively and the company was about to install an oil skimmer in the creek. According to company officials the material entrapped in the collection box was placed in drums for disposal off site. The disposal location for these wastes is unknown.

On January 17, 1979, a spill originating from a process room behind the offices (probably Building 91), had again entered Pierson's Creek. The spilled material reportedly contained mineral spirits, high flash naptha, oleic acid, naphthenic acid and alkali soluble methacrylate polymer. In addition, the overall conditions of the entire facility had deteriorated to its previous state. The company contracted Olsen and Hassold to contain the spill which, due to the large quantities involved, took more than a week to contain and remove. The spill reportedly extended downstream to Delancey Street. In response to the spill and the continuous discharges leaching from the walls of concrete flume, filter fences were installed by Olsen and Hassold. Leach boxes were also to be installed at the south side of the site.

A followup inspection on January 29, 1979, however, revealed another spill had entered the creek and again apparently originated from Building 91. According to Troy's maintenance personnel, they were ordered to pump this material into the stream because heavy rains caused flooding in the process building. Mr. Nowak, Vice President for the company, denied that the maintenance personnel had beeen ordered to discharge to the creek. The spilled material was subsequently rerouted to the company's pretreatment system under the direction of Mr. Faille and a contractor (Olsen and Hassold, Inc.) was hired to clean up the spill.

A followup inspection was performed by Mr. Faille on December 11, 1979. Although the overall facility conditions had improved, the pollution abatement systems installed in Pierson's Creek were not operating properly. Company officials reported they would repair these systems to proper operating conditions. However, a final inspection on December 13, 1979 by NJDEP personnel had revealed the conditions at the site were again deteriorating and the pollution abatement devices in the creek were not working properly.

Another noteworthy incident occured during an inspection by NJDEP personnel on June 2, 1977. At this time, Milton Nowak, Vice President of Troy Chemical, claimed that the only discharge entering the easternmost drainage ditch originated from a cesspool overflow. The exact location and current status of the cesspool is unknown. During the inspection, numerous discharges were also observed entering Pierson's Creek.

Based on the information available it is clearly evident that past and present activities by Troy Chemical have seriously impacted the quality of water and sediment in Pierson's Creek and its tributary, both onsite and downstream of the facility. The surface water in this area is used for recreational, industrial and commercial purposes.

AIR ROUTE

The NJDEP/Division of Environmental Quality has received numerous complaints concerning odors and releases from the Troy facility, however inspections conducted to verify these complaints have been inconclusive.

On August 30, 1983, an explosion in one of the reactor vessels resulted in a release of contaminants including butyl isocyanate into the atmosphere. Although the exact cause of the explosion was not determined, it was believed an improperly operating agitation unit within the reactor was at least partially responsible. According to company officials the reactor contained hydroiodo propene which was dissolved in high flash naptha. The reactor was then charged with butyl isocyanate which normally results in an exothermic reaction. Apparently the mixture was not properly agitated, allowing a layer of butyl isocyanate to form and causing the reaction to proceed with an increase in heat and pressure which could not be controlled by the cooling coils. According to reports, the entire contents of the reactor vessel was emptied in the explosion.

Improperly operating muffle type mercury recovery furnaces have also resulted in atmospheric releases of contaminants. On May 28, 1981 a stack test was performed on the three recovery furnaces to determine if mercury vapors were being emitted. The furnaces had been operating for approximately two years under a temporary certificate (#40322) prior to the stack test. The furnaces were designed to recover mercury from various solid materials including sludges and batteries. These materials would be placed on a pan which was sealed inside the furnace. The furnace was heated by underfired gas burners to a temperature where the charge material (sludge and batteries) reached the vaporization point of mercury. At this point the mercury to be recovered volatilized resulting in mercury emissions which were run through a series of water cooled condensors. The liquified mercury was then collected from the condensors. However, during the stack test it was noted very little flow was being emitted through the ejector Venturi Scrubber where the emission test was to take place indicating emissions were leaking from the system before reaching the air pollution control device (the scrubber). It was determined mercury contaminated emissions were leaking from the charge doors on the furnaces. It was also believed that contaminants other than products of combustion were being emitted from the stacks. As a result of the improperly operating furnaces and control devices, notices of violation were issued to the company by the DEQ and it was recommended further stack testing be conducted prior to issuance of an approved permit (certificate). According to the Division of Environmental Quality's stack log for the company, the muffle furnaces were deleted from active operation on June 12, 1985. It is unknown if a subsequent stack test was ever performed on these furnaces.

To date, no environmental air sampling data for the site is available.

It should be noted that 74 stacks are listed on DEQ's stack log for the facility. Of the 74, 59 currently have certificate (permit) numbers although many have been deleted (currently inactive) and others are temporary. The sources of the stacks include but are not limited to, above ground tanks, reactor vessels and furnaces.

During a October 6, 1989 NJDEP,BPA Presampling Assessment (PSA) ambient air readings of up to 18 ppm on the OVA as methane and over 20 ppm on the HNu as isobutylene were observed. Additonally, numerous point sources of elevated readings were noted as well as a strong paint or acrylic odor.

SOIL

Much of the site was recently paved, thereby covering most of the exposed soil surfaces; however, inspections by the NJDEP in the late 1970s and early 1980s revealed visibly contaminated soil throughout the site, apparently the result of spills, leaks and overall poor housekeeping. On numerous occasions leaking drums were observed being stored on the exposed ground surface. Many areas of the site were also noted to contain mercury droplets.

On May 7, 1976, it was reported that cobalt hexoate and calcium hexanoate were leaking from one of the tank farms into the surrounding soil, eventually discharging into one of the on site drainage ditches. Reportedly the contaminated soil was subsequently removed and disposed of at Kin Buc Landfill in Edison, New Jersey. Apparently no analysis of the soil in this area was performed before or after it was removed, therefore it cannot be determined if all the contaminated soil was properly removed.

In September 1977, the company collected soil samples at various locations throughout the site. These samples were analyzed for mercury content only. Concentrations of mercury ranged from 0.046 ppm in the sample identified as Clean Fill #2 collected near the polyphase plant, to 0.55 ppm in the sample indentified as Container #1 taken near Avenue L. The sample collection procedures and exact sample locations are unknown.

On April 28, 1989, NJDEP collected four soil samples in addition to the surface water samples which were referenced previously. The data is summarized on Table 8. The most contaminated of the four samples was collected near an onsite dumpster. The exact location of this dumpster is unknown. This sample was analyzed for copper, lead, arsenic, mercury, pesticides and volatile organics. As indicated in Table 8, seven of the contaminants detected were above the NJDEP/Recommended Cleanup Levels for these contaminants. In fact, the concentration of each individual volatile organic detected was above the cleanup level for total volatiles of 1 ppm. Relatively high concentrations of DDT and many of its breakdown products were also detected. Another highly contaminated sample was collected on the south side of the Fungicide Plant. This sample was analyzed for copper, lead, arsenic, zinc and mercury, with the concentrations of copper, lead, zinc and mercury above the NJDEP recommended action/cleanup levels.

Two soil samples were also collected from drum storage areas where obvious spillage had occurred. One of the storage areas is located on the south side of the Warehouse Building. The sample collected from this location was analyzed for copper, lead, arsenic, zinc, mercury, pesticides and volatile organics. The concentrations of copper, zinc, mercury and total volatile organics (as well as benzene and methyl isobutyl ketone, individually) were above the NJDEP recommended action/cleanup levels. The second drum storage area where a sample was collected was located in the "yard area", however it is unknown exactly where the yard area is located within the site. The sample collected from this area was analyzed for copper, lead, arsenic, zinc, mercury and volatile organics. Only the level of mercury exceeded the NJDEP action/cleanup levels.

Since each of these four samples was labeled as a composite sample, the concentrations reported were probably lower than the actual concentration due to the dilution which occurs when samples are composited.

During the November 17, 1989 NJDEP/BPA Site Inspection, five soil samples were collected and analyzed for the TCL plus 30 peaks and PHCs. Soil-1S and Soil-1D were collected in the north-central portion of the site to the west of Pierson's Creek at depths of 8 to 10 inches and 16 to 18 inches, respectively. Both samples showed concentrations in excess of clean-up levels for volatile and semi-volatile organic compounds, numerous heavy metals and PHCs. The shallow sample showed consistently higher levels than the deep samples for the majority of contaminants detected. Soils 2 and 3 were also located in the north-central portion of the site but on the east side of Pierson's Creek, with Soil-2 being slightly to the north of Soil-3. Soil-2 was collected at a depth of 12 inches while Soil-3 was collected at 0 to 6 inches. Low, but detectable, levels of some semi-volatile organic compounds and pesticides were found in both samples. In Soil-2, lead (153 ppm), mercury (355 ppm) and PHCs (340,000 ppb) were detected above clean-up levels. Also above clean-up levels in Soil-3 were: lead (246 ppm), mercury (736 ppm) and PHCs (960,000 ppb). Soils-4 and 5 were collected along the southern border of the site. Soil-4, which was collected at a depth of 2.5 feet, showed detectable levels of semi-volatile organic compounds as well as elevated levels of barium (1320 ppm), copper (174 ppm), lead (3920 ppm), mercury (2590 ppm) zinc (1320 ppm) and PHCs (4,4000,000 ppb). Soil-5 was collected in the western portion of the site at a depth of 6 inches. Analysis revealed detectable levels of volatile organics and elevated levels of semi-volatiles, arsenic (55.7 ppm), barium (584 ppm), copper (185 ppm), lead (2840 ppm) mercury (210 ppm), zinc (1835 ppm) and PHCs (14,000,000 ppb). Complete results of all soil samples can be found on Table 11.

Sampling events over the years have confirmed widespread, extreme contamination of substances that can be directly attributed to Troy's processes such as copper, lead, zinc, mercury and benzene.

Since most of the surficial soil throughout the site actually consists of fill material, the potential for many of the contaminants to migrate vertically through the soil column is magnified. Therefore, it is likely contamination present in the surficial soil is at least one of the sources the documented groundwater contamination.

It should be noted that the origin of fill material at the site is unknown.

DIRECT CONTACT

Two incidents of direct contact attributable to the Troy Chemical Company have been reported.

The first occurred on August 30, 1983 when an explosion in one of the reactors resulted in the release of contaminants including butyl isocyanate, hydroiodopropene and high flash naphtha. This incident was discussed in the section on Air Route. According to the NJDEP/Trenton Dispatch Incident Report concerning a complaint from a nearby resident, a giant coral-colored cloud was observed emanating from the company. This was followed by a gray mist and, according to the Incident Report, caused the complaintants eyes to burn. The exact number of people affected during this incident is unknown.

The second incident occurred in October of 1980. According to reports received by the NJDEP, an employee of the company was being treated for a severe case of mercury poisoning (100 ppm in the bloodstream). The cause of the poisoning was apparently a result of unsafe operational practices by the company.

The potential for offsite personnel to come into contact with hazardous materials on site is limited as the site is surrounded by a fence and security personnel are present 24 hours/day. However, offsite personnel may encounter hazardous substances which have migrated off site via Pierson's Creek.

As can be seen by the August 1983 incident, nearby populations including the transient populations at the Newark Airport and the New Jersey Turnpike are also susceptible to sudden atmospheric releases of hazardous materials from the company.

FIRE AND EXPLOSION

At least one fire and one explosion have been reported at the site.

The fire occurred in a manufacturing area on November 1, 1984, apparently the result of sparks from a compressor igniting solvents used in the machinery. Troyson Lead 36% was being filtered at the time of the fire. The fire was reportedly contained by the on site sprinkler system, however the Newark Fire Department assisted in controlling the fire. Minor spillage of unknown chemicals occurred during the incident, some of which may have entered the sewage system via runoff.

An explosion occurred on August 30, 1983 but will not be discussed in this section as it was previously discussed in the Air Route section.

Additonally, an employee interviewed during the October 6, 1989, NJDEP, BPA stated that there had been numerous explosions in Building 91 in the past.

Due to the nature (flammables, reactives, combustibles etc.) of materials used and stored by the company, a potential for future fires/explosions exists. Past inspections by the NJDEP revealed that extremely poor housekeeping practices employed by the company had permitted many chemicals to intermix. If similar conditions persist, which is likely, incompatible materials may mix resulting in potentially explosive and/or hazardous conditions.

OTHER CONSIDERATIONS

DAMAGE TO FLORA AND FAUNA

The deterioration of water quality in Pierson's Creek as a result of releases of hazardous substances may have a detrimental impact on aquatic biota in the creek. Aquatic organisms in Newark Bay may also be affected since Pierson's Creek discharges to the bay.

Migratory bird species are also susceptible to damage as the site lies along the flyway for many of the birds and hazardous substances, especially from spills and leaks, are easily accessible to the birds.

CONTAMINATION OF FOOD CHAIN

The presence of many bioaccumulative and biomagnification threats such as DDT, mercury and lead in soil, surface water and sediment leads to a potential for food chain contamination. The aquatic ecosystems of Pierson's Creek and Newark Bay appear to be the most susceptible to food chain contamination.

DAMAGE TO OFFSITE PROPERTY

The Albert Steel Drum/Prentiss Drug Site located directly north of Troy Chemical was recently acquired by the Newark Housing and Redevelopment Authority for redevelopment. During an investigation of the property by the Newark Engineering Department and the U.S. Attorney's Office on June 8, 1979, hundreds of bags labeled "Troysan-Mercury Acetate" were found strewn throughout the Albert Steel Drum/Prentiss Drug Site. The bags were reportedly empty (unused) but a silver gray material was observed on the ground surface in the vicinity of the bags. Samples of the silver gray material were collected and analysis revealed the presence of phenylmercuric acetate and high concentrations of mercury (0.5% or 5000 ppm). Since mercury and phenylmercuric acetate are major components of Troysan, it is likely the silver gray material was off-spec Troysan and was disposed of on the Albert Steel Drum/Prentiss Drug Site with excess container bags. It is probable other wastes from Troy Chemical were also disposed on the Albert Steel Drum/Prentiss Drug Site.

During many of the previous inspections at the Troy site by the USEPA and NJDEP, in which stream and/or sediment samples were collected from Pierson's Creek, background (upgradient) samples were collected from Pierson's Creek on the Albert Steel Drum/Prentiss Drug Site. Since many of the Troysan bags and the silver gray material observed on the Albert Steel Drum/Prentiss Drug Site were found near the drainage ditch (Pierson's Creek), it is questionable whether the upgradient samples actually monitor background conditions, as it appears Troy Chemical is at least partially responsible for upgradient (background) contamination.

In addition, the migration of contaminants offsite via Pierson's Creek may also have impacted downstream offsite properties.

CONTAMINATION OF SEWERS, STORM DRAINS, WWTPs

As was previously stated, Troy Chemical was issued a sewer connection permit (#204013290) to discharge treated process wastewater, various blowdowns and sanitary sewage to the Passaic Valley Sewage Commission (PVSC) Treatment Plant. The discharge to PVSC is monitored continuously for LEL and pH as well as quarterly for BOD, TSS and petroleum hydrocarbons. The discharge was formerly monitored triweekly for mercury prior to the cessation of the mercury processes. This permit is in conjunction with the NJPDES permit by rule category which delegates regulatory responsibility for discharge to an approved Publically Owned Treatment Works (POTW) to the POTW itself. In addition, as per federal regulations, the POTW is required to develop an Industrial Pretreatment Program (IPP) ensuring contributor compliance with the POTW regulations. On numerous occasions Troy Chemical has exceeded limitations of these permits allowing contamination, including excessive quantities of mercury, to be discharged to the sewage system.

Prior to connection to the PVSC sewage system, process wastewaters were discharged to Pierson's Creek and sanitary wastes to the onsite septic tank/leach field system. The leach field system apparently also discharged to Pierson's Creek; however, Newark City ordinances prohibited the use of septic systems in areas serviced by sanitary sewers and New Jersey State Regulations prohibited the use of septic systems in flood prone areas. Since the company was in violation of both state and local regulations they were required to tie into the PVSC system. The exact date in which they were permitted to tie into the PVSC system is unknown; however, as early as March of 1977, a former Troy Chemical employee alleged that the company's newly installed septic tank was actually tied into the sanitary sewer system. The septic system reportedly had a cutoff valve which permitted wastes, including biocides and flammables to be discharged to the sanitary sewer system at will; however, these allegations could not be substantiated.

A sample of the discharge to the city sewer was collected by the NJDEP on September 1, 1977 and analyzed for iodine, mercury, zinc, chromium (hexavalent and total), sulfate, chlorides, volatile organics and a variety of indicator parameters including pH. Analysis of the sample revealed low concentrations of mercury, total chromium, lead and zinc and 17,400 ppm of chloride. The volatile organic analysis was postive for methylene chloride and carbon tetrachloride. The pH of the sample was 11.6, which is above the current sewage connection permit limitation; however, it is unknown what the permit limitation for this parameter was at the time of the incident.

On August 2, 1979, a discharge to the sewage system was again collected by the NJDEP. This sample was analyzed for volatile organics, mercury, total chromium, arsenic, and oil and grease. A field pH of this sample was reported to be over 12.0. Extremely high concentrations of benzene (1,350 ppb), tetrachloroethylene (1,368 ppb), 1,2-dichloroethene (19,250 ppb), and oil and grease (367 ppm) were detected in this sample. Low concentrations of total chromium and arsenic were also detected. Due to interference, the concentration of mercury in the sample could not be determined. Of greatest significance in this sample is the presence of volatile organics which either entered the sewage system through the company's sanitary sewer discharge or the chemical sewer discharge. If these contaminants originated from the chemical sewer, which enters into the overall plant wastewater treatment system, it could be concluded that this treatment system is not effective in removing all solvents, especially those more dense than water. If the contaminants originated from the company's sanitary system this may have represented a continuous illegal discharge to the public sewage system.

From January 1979 to May 1979, the PVSC conducted investigations of Troy's discharges by collecting numerous 24 hour composite samples from the manhole outside of the Troy site. All of the samples were analyzed for mercury with the results revealing concentrations of mercury ranging from 57 ppm to 365 ppm. It should be noted that these samples were analyzed by three different laboratories and although the concentrations detected by the different laboratories varied somewhat, the levels of mercury in all of the samples were cause for concern. Based on this analysis, it was estimated that the company was discharging 327 pounds of mercury to the sewage system each day. Since the PVSC system offered only primary treatment at this time, approximately 90% of this mercury was being discharged with the effluent to Newark Bay.

Although the concentrations of mercury discharged had diminished considerably since this investigation, the sewage connection permit limitation of 0.4 lbs per day was exceeded on numerous occasions from 1984 to 1986. During the monitoring period from April 1, 1986 to June 30 1986, the mercury limitation was exceeded on 59 of the 60 analyses performed.

In addition, changes to the PVSC rules and regulations in 1984 limited the amount of flammable materials which could be discharged; however, inspections of the LEL instruments installed on site by PVSC personnel had revealed the instrument has not operated properly since its installation. On occasions when the instrument was functioning properly, readings as high as 48% LEL were recorded indicating flammables were being discharged. It should be noted that during two of the PVSC inspections, the manhole cover to the sewer line where the LEL meter was situated was removed allowing the flammables to vent and resulting in lower than actual readings. It is likely this was a common practice by the company in order to achieve compliance with the LEL limitations since the LEL concentrations were recorded continuously on a strip chart which was then inspected by PVSC during their inspections.

Other violations of PVSC rules and regulations and permit conditions included deficiencies of the Baseline Monitoring Report (sewer permit equivalent to NJPDES Discharge Monitoring Report) and excursions of pH limitations.

Deficiencies of the Baseline Monitoring Report included the aforementioned excursions of mercury limitations, not properly preserving samples and not submitting the Monitoring Reports on time. The pH limitation was exceeded on September 9, 1986 when the pH of the discharge was reported to be above the permit limit of 10.5 for almost 1.5 hours prior to the PVSC being notified. According to Troy officials, the excursion was a direct result of a faulty pH meter registering false readings.

UNSTABLE CONTAINMENT OF WASTES

As previously addressed, waste management practices by the Troy Chemical Company, especially prior to 1986, have been inadequate and have contributed to soil, air, surface water and groundwater contamination. Many of these practices were referenced in previous sections and therefore will only be discussed briefly here.

Site conditions were best exemplified in various reports concerning inspections conducted by the NJDEP and the USEPA in the late 1970s and early 1980s. Although the numerous inspections spanned a period of greater than five years, overall site conditions remained relatively unchanged. Included in many of these inspection reports was reference to 4000 plus drums of wastes, raw materials and unknowns which were being stored throughout the site. Many of the drums were also reported to be in poor condition and were leaking. Since many of the drums were being stored on the unprotected ground surface, leaks and spills from the drums may have had a direct impact on soil contamination at the site.

In addition to the overall poor conditions of drums, tanks, etc. and the poor operational practices undertaken by the company, the inadequacy of secondary containment should also be considered. As was stated previously, many of the drums were stored on the unprotected ground surface, and even in areas where wastes were being stored on concrete or asphalt, berms were either non existent, inadequate or insecure to contain spills or leaks. Inspections had also revealed numerous cracks in the containment walls surrounding the tank farms and, in some instances, materials were observed leaking from the cracks. Numerous pipes were also observed throughout the site, many of which were leaking or discharging untreated wastes directly to Pierson's Creek. It should also be noted that reference was made to waste pits on site during an inspection by NJDEP personnel on June 6, 1977. The location and current status of these pits is unknown.

Another point worthy of consideration is the ultimate fate of the spills, leaks, drums, etc. which were removed for offsite disposal. In many cases, especially that relating to the removal of the 4,000 plus drums, the actual fate of the materials could not be determined due to conflicting reports concerning the removal and disposal. One report claims approximately 1,000 drums were hauled offsite for disposal by the Lightman Drum Company to Chemical Waste Management in early 1980. A report dated June 19, 1981 again states approximately 1,000 drums were removed by the Lightman Drum Company, but the disposal location was not reported. It is uncertain if these reports are actually addressing the same removal episodes. Yet still another report dated December 13, 1979 by Mr. Edward Faille of the NJDEP stated wastes from thousands of the drums were disposal via the PVSC, but the exact method of disposal was not specified. If the wastes were disposed in the sewage system, it is likely this represented an unpermitted illegal discharge as file reviews did not reveal any approvals from the PVSC for such disposal. The company claims that no manifests for the removal or disposal of any of these drums are available.

ILLEGAL/UNAUTHORIZED DUMPING

Known and suspected instances of illegal/unauthorized dumping were also addressed in previous sections and include the disposal of Troysan on the Albert Steel Drum/Prentiss Drug Site and those incidents observed on the aerial photography.

One alleged incident of illegal disposal which has not been referenced in previous sections occurred in the early 1980s and involved disposal of mercury wastes in the on site dumpster. Allegedly, mercury wastes were mixed with sand in 55-gallon drums and disposed of in the dumpster. Surveillance by the NJDEP, however, could not substantiate these allegations.

ENFORCEMENT ACTIONS

Numerous enforcement actions have been levied against the company resulting from violations of NJPDES, RCRA, air quality and local sewage commission regulations. A brief outline of some of the past regulatory/enforcement actions and the issuing agency is as follows:

- Issuing agency: NJDEP/Division of Hazardous Waste Management

August 19, 1987 - Amended Administrative Order and Notice of Civil Administrative Penalty Assessment (AAO/NCAPA)for failing to conduct semi-annual drills with local emergency response agencies and for failing to include in their contingency plan the emergency actions to be undertaken by facility personnel in case of releases of hazardous materials.

July 6, 1987 - Administrative Order and Notice of Civil Administrative Penalty Assessment (AO/NCAPA) for failing to arrange hazardous waste containers so the identification label is visible and for the violations referenced above The violation for failing to arrange the containers properly was later rescinded resulting in the Amended Administrative Order of August 19, 1987.

July 10, 1984 - Notice of Violation (NOV) for failing to submit a TSD annual report for 1983.

- Issuing agency: EPA

June 16, 1981 - Complaint, Compliance Order, and Notice of Opportunity for a Hearing regarding storage of ignitable waste without rendering them non-ignitable or protecting them from ignition; failing to operate the facility in a manner which would minimize the possibility of fires, explosions, releases, etc.; lacking adequate internal communication/alarm systems; and for failing to take precautions to prevent accidental ignition of ignitable wastes.

- Issuing agency: NJDEP/Division of Environmental Quality

June 14, 1984 - Notice of Prosecution (NOP) for failing to obtain a permit to construct, install or alter control equipment from the Department.

August 27, 1981 - Notice of Prosecution (NOP) for allowing benzene to be emitted into the atmosphere without registering the equipment with the Department.

June 25, 1981 - Notice of Prosecution (NOP) for utilizing three muffled mercury recovery furnaces, one of which was functioning improperly thereby permitting emissions to escape from the charging door.

March 26, 1981 - Notice of Prosecution (NOP) for using a recovery furnace without the Venturi Scrubber in use or functioning properly; and for failing to obtain a "Permit to Construct, Install or Alter Control Apparatus or Equipment" and a "Certificate to Operate Control Apparatus or Equipment" from the Department prior to installing/using a carbon adsorbtion unit.

July 14, 1980 - Notice of Prosecution (NOP) for using a mercury still and condenser without water service to the water layer emission reducer.

January 18, 1979 - Notice of Prosecution (NOP) for failing to obtain a "Permit to Construct, Install or Alter Control Apparatus or Equipment" prior to installing an 1800 gallon reactor.

July 10, 1978 - Notice of Prosecution (NOP) for failing to obtain a "permit" or "certificate" prior to installing/operating control equipment.

- Issuing agency: NJDEP/Division of Water Resources

June 28, 1987 - Directive Letter issued as a result of observations made during a Compliance Evaluation Inspection requiring Troy to cease unpermitted discharges of boiler blowdown water and steam condensate to Pierson's Creek, provide a timetable for implementation of a Best Management Practices Plan; and to inform DWR of any future spills through written notification.

February 24, 1987 - Thirty day notice for failure to submit a Discharge Monitoring Report.

March 27, 1986 - Thirty day notice for failure to submit a Discharge Monitoring Report.

June 21, 1985 - Directive Letter to correct deficiencies noted during a Compliance Evaluation Inspection. Deficiencies cited included violations of permit limitations for COD, poor housekeeping throughout the site, and the use of the company's lab to perform the NJPDES analysis however the lab was not certified for this analysis.

- Issuing agency: Passaic Valley Sewage Commission

May 9, 1986 - Numerous deficiencies were noted during a compliance inspection regarding the use of an LEL monitor which resulted in submission of a violation letter by the PVSC.

August 17, 1986 - Violation of PVSC rules and regulations for failing to submit a Baseline Monitoring Report.

August 13, 1986 - Numerous deficiencies were again noted in the company's Baseline Monitoring Report. Most of the deficiencies regarded improper reporting of various aspects of the Baseline Monitoring Report.

August 18, 1986 - Violation of PVSC Rules and Regulations by exceeding limitations of mercury on 59 of 60 occasions for the period spanning 4/1/86 to 6/30/86.

It should be noted that the ultimate result of many these enforcement actions is unknown. However, some of the actions were rescinded as a result of corrective actions taken by the company.

PRIORITY DESIGNATION

Becuase damage to human health or the environment is not likely due to the location of the site in a highly industrialized area, a low pricity is assigned.

RECOMMENDATIONS

If feasible, investigation of this site should be coordinated in conjunction with the RI/FS at the adjacent Albert Steel Drum/Prentiss Drug Site. It appears these two sites were actually part of one large operation for a long period of time and therefore many of the problems associated with both sites may be comparable. Additional sampling to determine the vertical and horizontal extent of contamination may be necessary.

Further investigation of the suspicious areas observed on the aerial photography is also necessary. Boring and/or sampling, as appropriate, is recommended for these areas. A full photographic interpretation should also be included to identify other areas of concern(i.e. the cesspool as referenced during the June 2, 1977 inspection and the waste pits referenced during the June 6, 1977 inspection).

The company should provide unambiguous information concerning the removal and ultimate fate of hazardous and potentially hazardous materials from the Troy facility from 1956 to date. This information should include, but not be limited to, the removal and disposal of spills, contaminated soils, sludges, process wastes (filter paper, residues, etc.) and the 4000 plus drums.

A definitive RCRA/IWMF status should be applied to the facility to address the gray areas currently present in the regulations including tank storage and secondary containment issues. Also, the NJDEP/Division of Hazardous Waste Management/Bureau of Environmental Evaluation and Cleanup Responsibility Assessment should be notified as to the cessation of the mercury processes in 1987 to determine if ECRA status is applicable.

Future inspections of the facility should address operational practices and equipment utilized by the company to ensure proper measures have been undertaken by the company to eliminate the occurrence of releases and spills. Secondary containment should also be upgraded or repaired in response to the insecure conditions noted during previous inspections by the NJDEP.

The company's current SPCC plan is totally inadequate as it does not address potential releases or spills from "non-oil" related storage areas. Because of the enormous quantities of hazardous materials stored on site and the numerous releases from the storage areas in the past, a plan addressing all storage areas is necessary. Secondary containment of the oil/solvent storage tank should also be taken into consideration although IWMF regulations do not require secondary containment for this type of unit.

Further development of the site, including the planned redirection of Pierson's Creek should be restricted until all environmental concerns have been addressed.

Due to the documented contamination of the soil, sediment surface water and groundwater by a variety of hazardous constituents, the lead for this case should be assigned to the Bureau of Case Management (BCM) with a Responisble Party search referred to the Bureau of Compliance and Technical Services (BCTS).