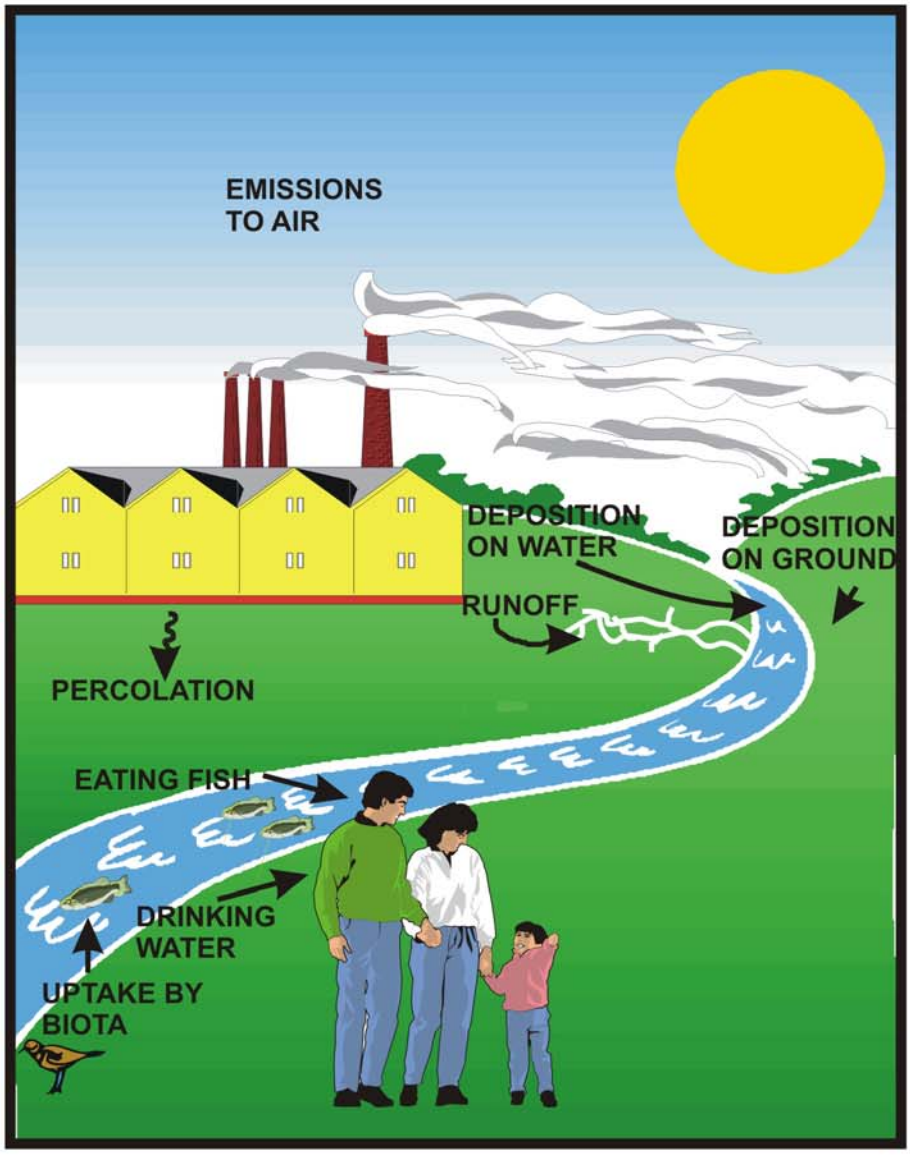
New Jersey Mercury Task Force

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

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Department of Environmental Protection

Robert C. Shinn, Jr.
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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

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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
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Volume III
Sources of Mercury to New Jersey's Environment

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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.

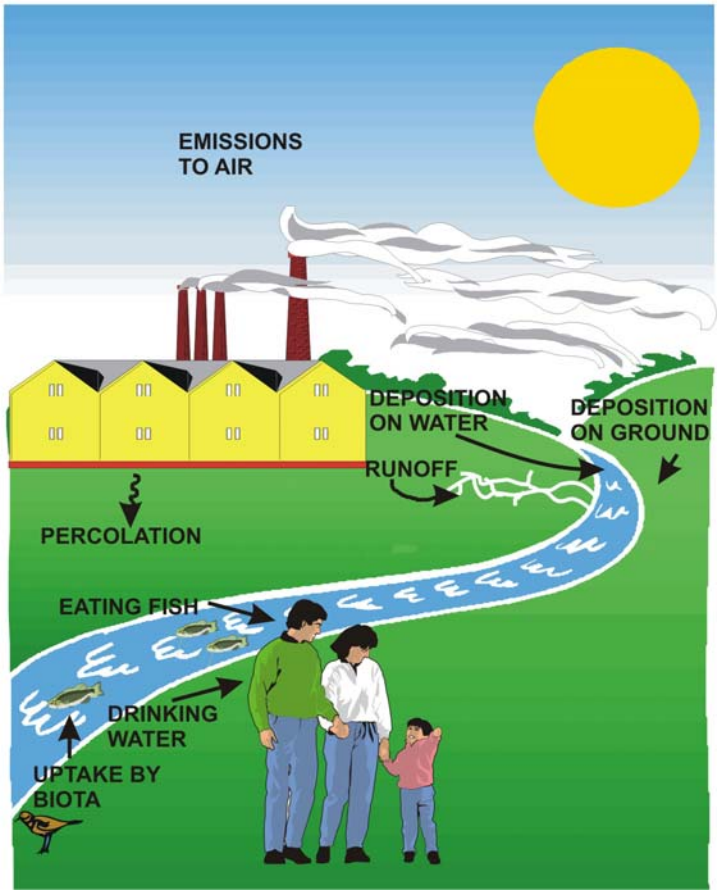


Table 2-1 shows how various sources contribute to potential exposure pathways for methylmercury (MeHg), ionic mercury (Hg^{++}), and elemental mercury (Hg^{0}). Where data are available, the table provides estimates of daily exposure relevant to New Jersey.

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 : g /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).

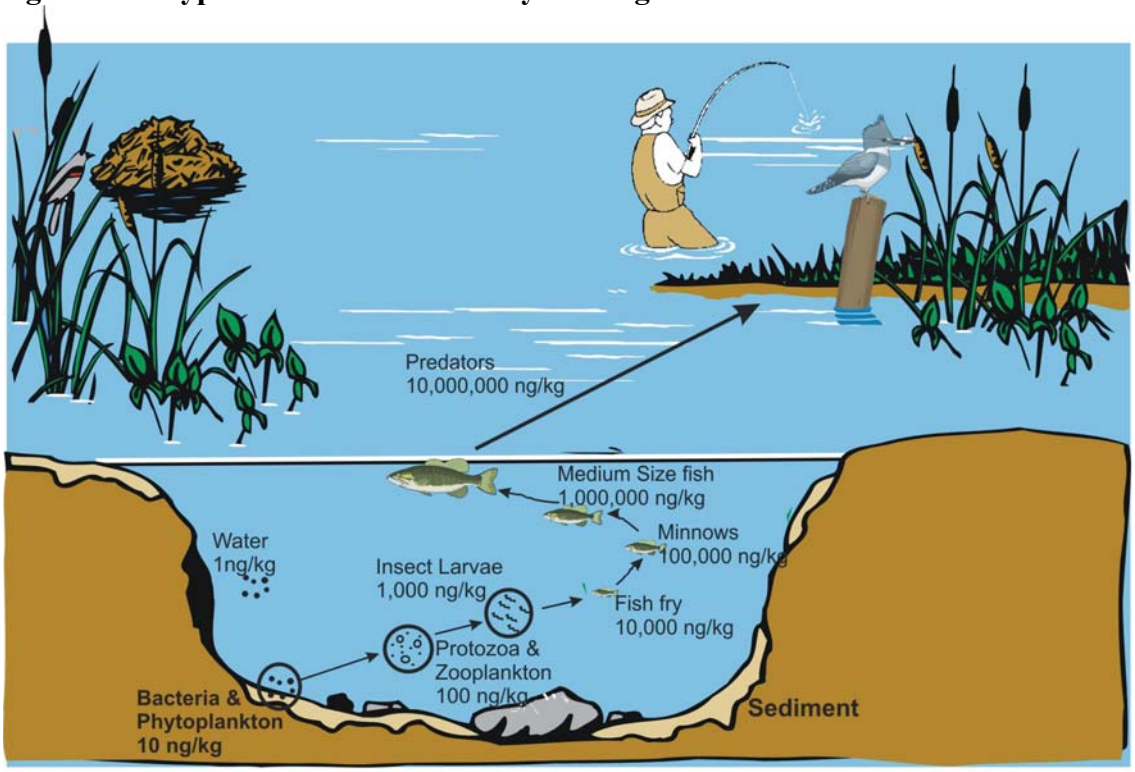
Substances that enter the intestinal tract or the lungs do not necessarily gain access to the blood stream or reach critical target organs. The amount that is transferred depends on two related phenomena: absorption and bioavailability. The intestinal tract and the lungs differ in their absorptive properties 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.



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 μg/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 x 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 ($\mu g/m^2/yr$)	Dry Deposition Rate ($\mu g/m^2/yr$)	Total Deposition Rate ($\mu g/m^2/yr$)
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 $\mu g/m^2/yr$ (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 $\mu g/m^2/yr$ and a range across 33 sites of 3.9 to 17.7 $\mu g/m^2/yr$ in 1999 (NADP, 2000). It is also well above the mean wet deposition in the United States and eastern Canada of 10 $\mu g/m^2/yr$ 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.

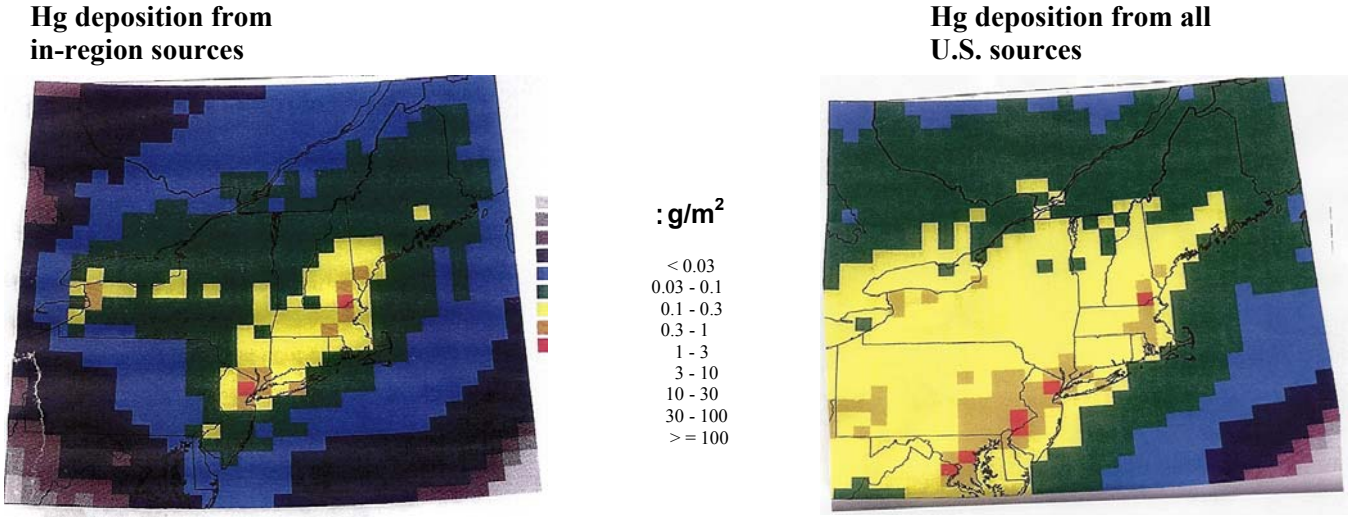
3. Relative Contributions of In-State and Out-of-State Emissions to Deposition in NJ

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 ($\mu g/m^2/yr$) 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.



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 12^{th} day at some of the sites, but a subset should be enhanced to collect particulate mercury data every 6^{th} 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 90^{th} 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 (75^{th} percentile of 131 g/day) consumption. White males consuming Bowfin and Bass at the 75^{th} 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 : g /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 : g /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 : g/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 (: g/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 : g/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 : g/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 : g/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 : g/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 : g /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 : g/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 : g/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 : g/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 Fg/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 0.1µg/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

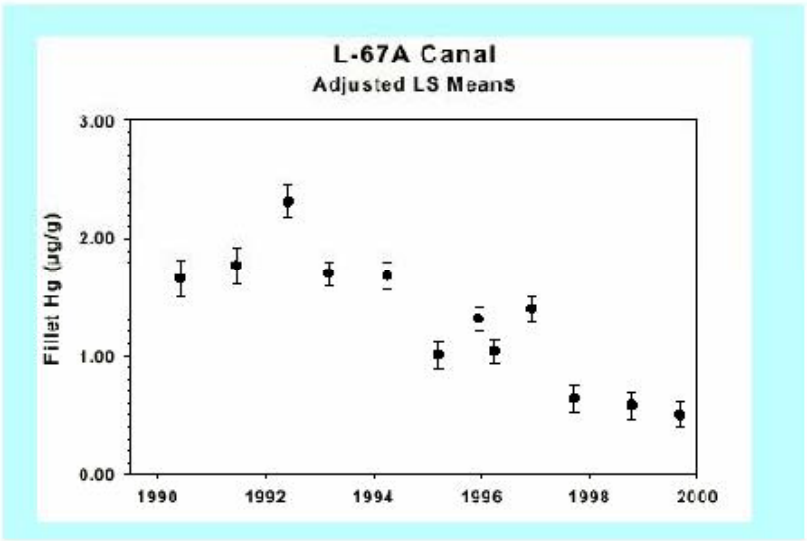
(including marine mammals). This should include the examination of ecosystem-level effects and the monitoring of tissue levels in target species to track long-term trends in mercury bioaccumulation. Tissue levels should be compared to national and international mercury reduction efforts and other media 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 : g/L	Median (: g/L)	Range (: g/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.

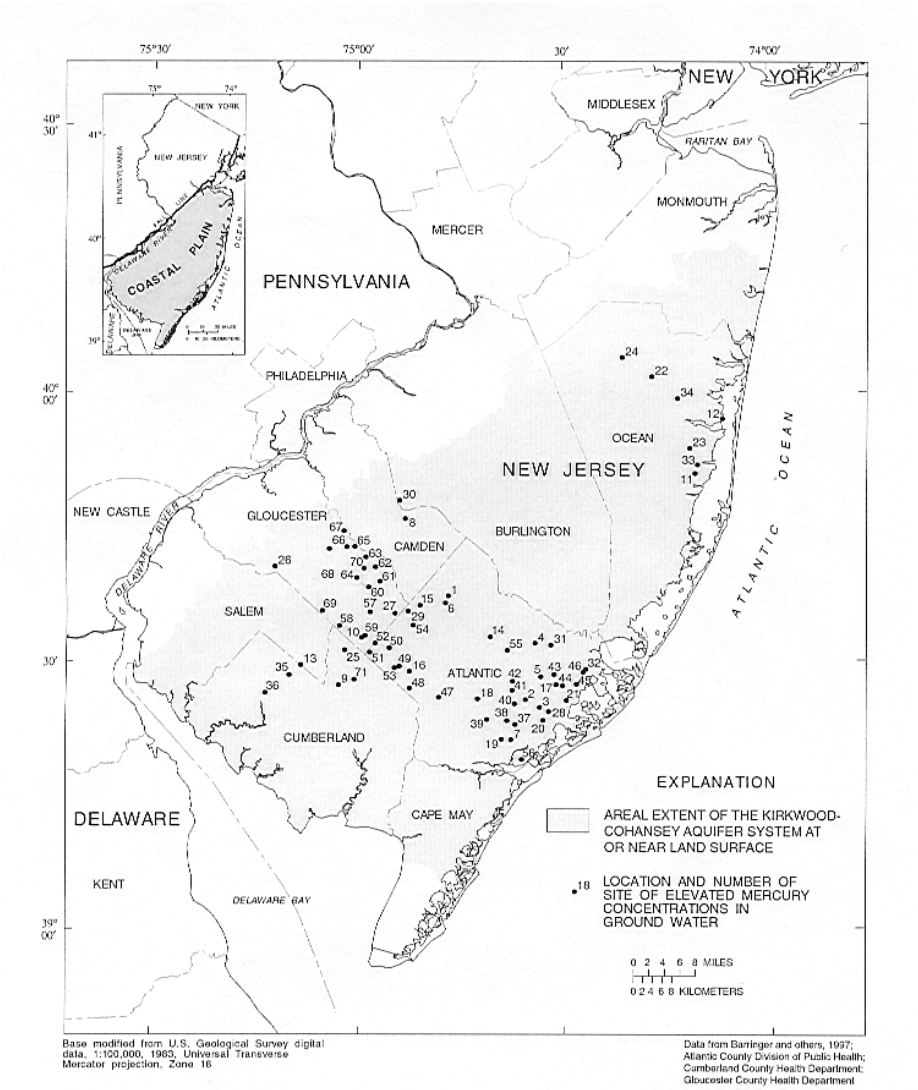


Figure 2.5. Locations of 71 Areas Where at Least One Well Contained Mercury Concentrations Above 2 ug/L. (Inset Map Shows Location of the New Jersey Coastal Plain.)

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 ꞉g/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

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 : g/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 : g/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 : g/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 : g/L. Therefore, the chronic aquatic life criterion could not be evaluated.

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

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

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.

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 : g/L / Total # Samples	0/12	4/12	10/12	11/12	11/12
Percent of Samples Exceeding 0.025 : g/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 : g/g (ppm) (NJDEPE 1993). The average mercury concentrations in sediments of three lakes in NJ were 0.13 ± 0.05 : g/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.

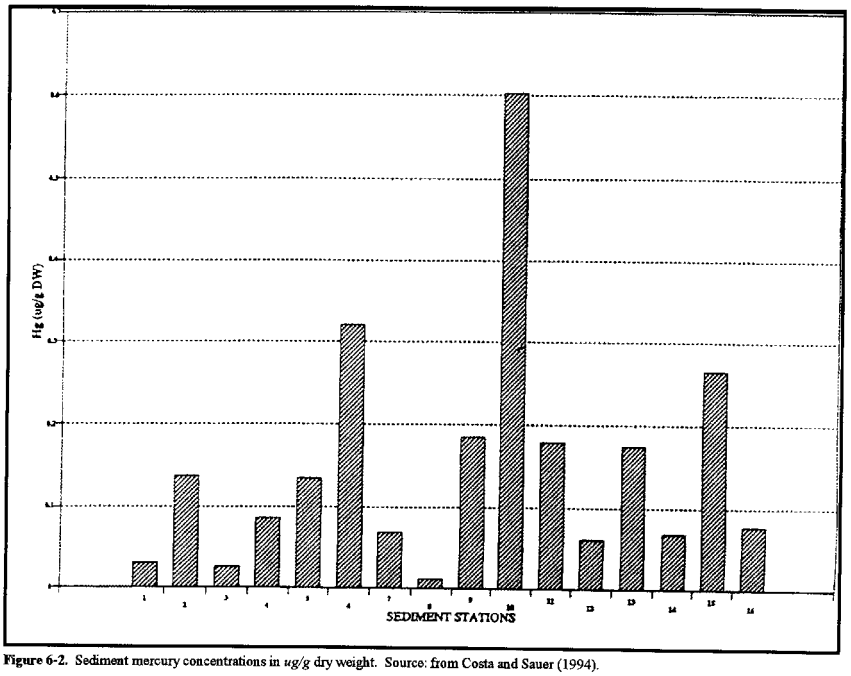


Figure 6-2. Sediment mercury concentrations in *ug/g* dry weight. Source: from Costa and Sauer (1994).

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=：g/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

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

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.

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., $\leq$ 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

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

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).

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.

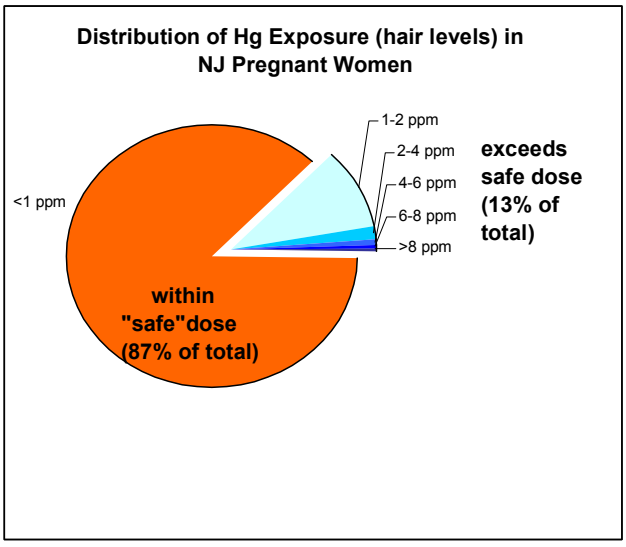
Table 2.28. Distribution of Total Mercury in Hair from the Sample of NJ Pregnant Women.

Mercury concentration (: g/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.

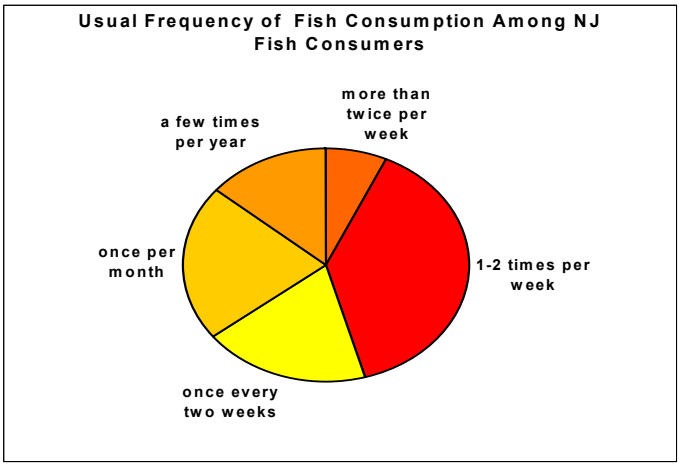
Mercury Concentration (: g/l – ppb)	Number (total = 149)	Unweighted percent of total	Age weighted percent of total	Race weighted percent of total	Education weighted percent of total
>0.25 - <1.0	127	85.2	76.9	84.4	83.6
1.0 - < 5.0	15	10.1	14.8	10.9	10.1
5.0 - <10	5	3.4	5.6	3.2	5.0
$10	2	1.3	2.6	1.6	1.3

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 : g Hg/L blood (S.E. = 0.28 : g /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 : g /l, and two had concentrations greater than 10 : g /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 : g Hg/g hair (S.E. 0.07 : g/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 : g/g and 2% had concentrations greater than 4.0 : g/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 : g/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 : g/g and approximately 5% had levels greater than 2 : g/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 : g/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 : g/L (ppb) and hair mercury concentrations greater than 1.0 : g/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; 90^{th} 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 (: g/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	
	(: g/day)	(: g/day)	(: g/kg/day)	(: g/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 (: g/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 : g/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 : g/kg/day for all adults and 0.09 : g/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 : g/l) in some private wells in southern NJ. The highest total mercury concentration in wells was 36 : g/l and the mean total mercury concentration among those wells exceeding 2 : g /l was 8 g : /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 : g /L (maximum=0.4 : g /L). For water containing 5.0 : g/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 : g/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 : g 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 extrernally 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 ：g/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 ：g/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 ：g/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 : g/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 : g/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 : g/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 : g/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 : g/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 (: g/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 : g/kg/day - ~1 : g Hg/g hair)	10-15%	21%
Average maternal hair mercury in Faroe Is. - 4 : g/g (~0.4 : g/kg/day)	1-2%	1-3%
Doubling of proportion of children in the lowest 5% of neurologic performance (~4 : g/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

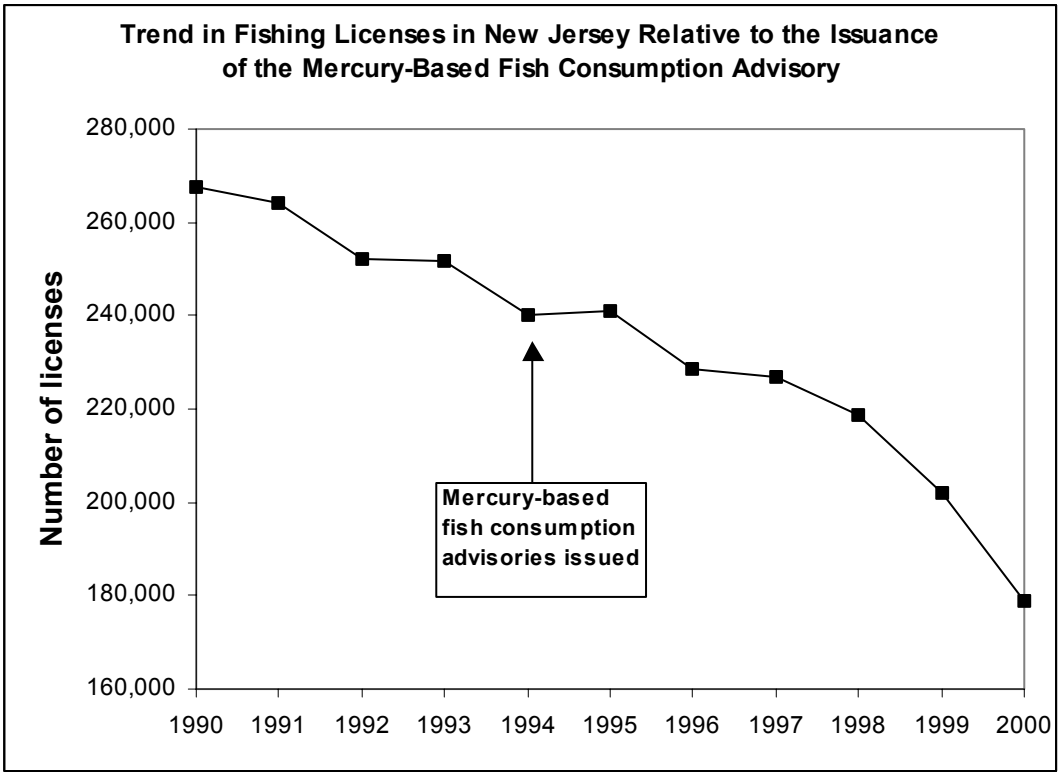
2. Trends in Fishing Licenses and Fishing Statistics

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

Fg	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

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