

DRAFT PAPER
FOR DISCUSSION PURPOSES ONLY

Nonpoint Source Pollution: Air and Land Dimensions

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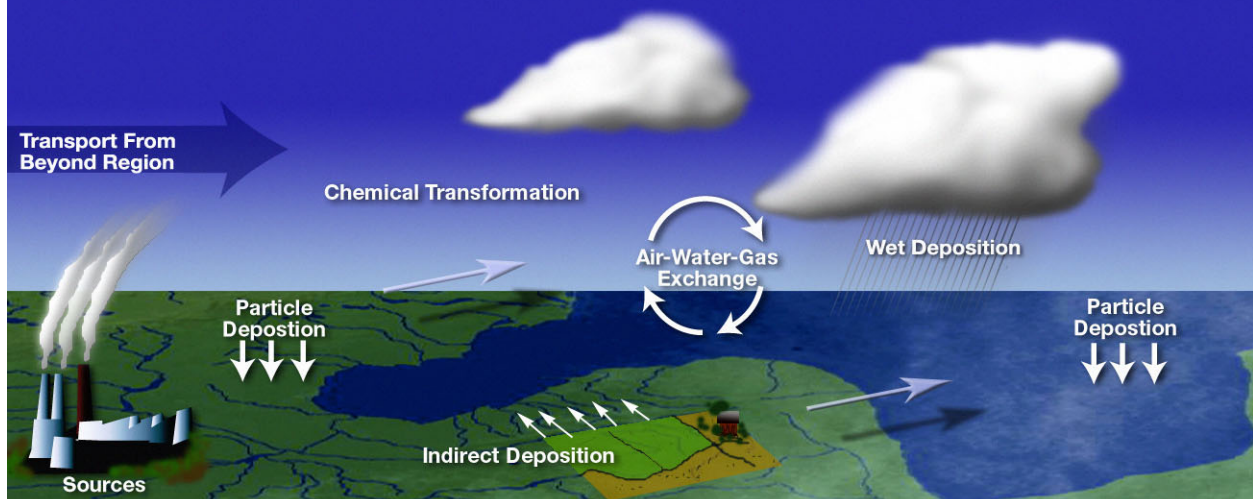


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I. INTRODUCTION

A. Current Understanding

1. Nonpoint Source Pollution

Nonpoint source (NPS) pollution of the Great Lakes, unlike pollution from specific and identifiable industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. EPA (1994) specifies that NPS pollutants include:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septic systems;
- Atmospheric deposition and hydromodification are also sources of nonpoint source pollution.

Water pollution occurs from point and non-point sources. Point source pollution comes from a finite source, such as an intensive livestock operation, and can be managed by regulating the source. Non-point source pollution (NPS) comes from diffuse or scattered sources in the environment rather than from a defined outlet such as a pipe. As water moves across and through the land it picks up and carries away natural and human-made pollutants, depositing them into lakes, rivers, wetlands and coastal waters.¹

Pathways of pollution, in regards to the Great Lakes, are of special concern. Unlike rivers that run to the oceans, The Great Lakes represent the end of the pathway. Their place in the ecosystem means that regardless of whether pollutants are diluted by large stream flows or temporarily stored on sediment particles on stream bottoms, eventually they will reach the lakes and add to the total contaminant burden.

Groundwater movement is one of the pathways for pollutants to enter the Great Lakes. Water moving slowly through the ground can pick up dissolved materials, carrying them in mass. Widely a localized phenomenon, ground water contamination prevention is the best approach to management.

¹ What is Nonpoint Source Pollution? US EPA. <http://www.epa.gov/region4/water/nps/>

Another pathway for a significant variety of substances to enter the lakes is through surface runoff. Agricultural activities release nutrients, pesticides and soils and urban areas contribute street runoff from automobile-related substances such as salt, sand, asbestos, cadmium, lead, oils and greases. Surface runoff also includes a wide number of materials deposited with precipitation, which may include particulates, bacteria, nutrients and toxic substances.²

While acknowledging the challenges in tracking, evaluating, and reporting the implementation of NPS control measures for urban, agricultural and forested regions of the Great Lakes³⁴⁵ this paper focuses on the issue of atmospheric deposition as important sources for NPS of a number of toxic pollutants.

2. The Role of Atmospheric Input

While efforts have been undertaken to reduce point sources of pollution and to study non-point pollution sources, it was also discovered that many pollutants are deposited from the atmosphere.⁶ Once airborne, pollutants may fall to the ground in a process called atmospheric deposition. Atmospheric deposition can be divided into direct and indirect deposition. Direct deposition can be either wet or dry and is defined as pollutants entering the waterbodies by falling directly into it from the atmosphere. Indirect deposition comes from pollutants falling onto land and washing into a body of water as runoff. Wet deposition occurs when air pollutants fall with rain, snow, or fog. Dry deposition is the deposition of pollutants as dry particles or gases.⁷

During the mid-1980s, atmospheric deposition and its potential impacts to the Great lakes was recognized as significant and, in some cases, dominant. In a study by W. M. J. Strachan and S. J. Eisenreich in 1988, inputs of wet, dry and gas flux deposition of atmospheric toxics to each of the lakes was estimated. Strachan and Eisenreich found that up to 96% of the PCB inputs to the

² The Great Lakes: An Environmental Atlas and Resource Book. ("Great Lakes Atlas") 1995. Government of Canada and the United States Environmental Protection Agency. <http://www.epa.gov/glnpo/atlas/glat-ch4.html>

³ Techniques for tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Agriculture, Office of Water, EPA 841-B-97-010.

⁴ Techniques for tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Forestry, Office of Water, EPA 841-B-97-009.

⁵ Techniques for tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban, Office of Water, EPA 841-B-00-007.

⁶ The Great Lakes: An Environmental Atlas and Resource Book. ("Great Lakes Atlas") 1995. Government of Canada and the United States Environmental Protection Agency. <http://www.epa.gov/glnpo/atlas/glat-ch4.html>

⁷ Atmospheric Deposition and Water Quality. US EPA. <http://www.epa.gov/owow/oceans/airdep/air1.html>

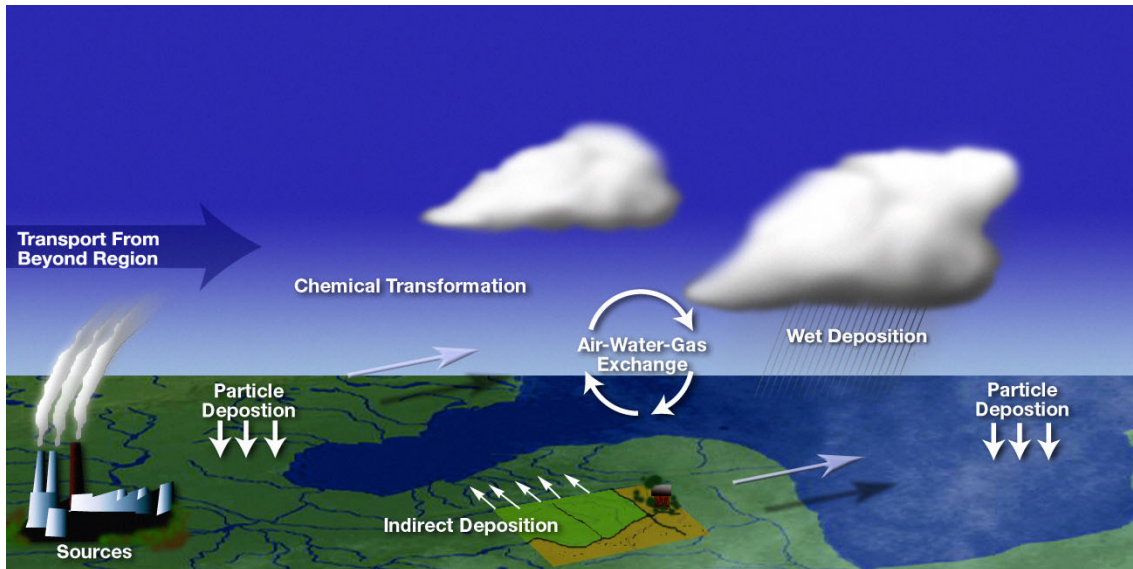


Figure 1. Processes involved in the atmospheric deposition of toxics into the Great Lakes system.

lakes were atmospheric in origin.⁸ This work alone had considerable influence on the creation of new monitoring and research programs in the US and Canada.⁹

The connection between the emissions of a pollutant and its deposition are often difficult to make. Once in the atmosphere, emissions from a particular source may spread over a large area and deposit in several watersheds. Additionally, rates of deposition are impacted by the convergence of proper meteorological patterns and emissions sources. That being said, reducing emissions in specific areas does lead directly to reducing deposition rates in that area. For example, when large reductions in sulfur dioxide emissions were implemented in the Ohio River Valley, a significant drop in sulfate deposition was measured downwind in the highly sensitive Adirondacks and New England.¹⁰

There are many studies linking atmospheric deposition and impacts to the environment. For instance, it is well known that nitrogen-rich rainwater is likely to produce significant algal growth when added to seawater.¹¹ Tracing these pollutants from birth to death is not so easy though. Distinguishing between air-deposited pollutants and those pollutants that entered the waterbody through other pathways is difficult. Modeling is the primary tool used to provide these connections.

Atmospheric deposition monitoring and modeling studies confirm that, while runoff and discharges of pollution into waterways are a significant problem, atmospheric deposition of

⁸ Strachan, W. M. J. and S. J. Eisenreich, 1988

⁹ R. M. Hoff et al., 1996

¹⁰ Frequently Asked Questions about Air Deposition: A Handbook for Watershed Managers. US EPA. 2001.

¹¹ Frequently Asked Questions about Air Deposition: A Handbook for Watershed Managers. US EPA. 2001.

pollutants is a significant pathway to waterbodies. These studies also show that the atmospheric deposition of pollutants is highly variable, depending on the pollutant being studied. For example, the atmospheric deposition of dioxins and furans entering the Great Lakes varies between 5 and 100 percent depending on the location of the monitoring site.¹²

In a study on mercury by the US EPA, fate and transport modeling and exposure assessments were used to predict the anthropogenic contributions of methylmercury in fish. It was found that mercury emissions from industrial and combustion sources increase mercury concentrations in fish. Additionally, the consumption of fish by humans and wildlife was determined to be the primary pathway that mercury found its way into the food chain. At the time, mercury was known to cause environmental problems and it was understood that atmospheric deposition of mercury was a pathway for it get into the food chain. Thus a connection was formed between mercury and atmospheric deposition¹³.

Atmospheric deposition in the Great Lakes was first recognized with phosphorous. Research showed that roughly 20 percent of the phosphorous loading to Lake Michigan entered the system as rain, snow or dust fall. In 1971, atmospheric deposition of toxic chemicals was determined after measurements of PCBs in precipitation lead to Great Lakes fish contamination. Perhaps most telling though, a study in Isle Royale, a remote island in Lake Superior isolated from any known source of pollutants, found PCBs and toxaphene in fish from an inland lake.¹⁴

An additional challenge to studying atmospheric transport of substances is the fact that many substances do not stay dissolved in water. The volatilization of PCBs back into the atmosphere leads to large quantities of synthetic organic chemicals moving around in regional and global air masses. This constant flux of toxic contaminants varies itself based on weather and temperature on a global, not local basis.

Air deposition of pollutants is not simply a problem for the Great Lakes. The nation's coastal systems, in particular the estuaries, are at significant risk to atmospheric pollutant deposition too. National Estuary Programs (NEPs) are addressing air deposition as part of their analysis of the threats facing their estuaries. On the East and Gulf Coasts, NEPs including Corpus Christi Bay, Galveston Bay, Tampa Bay, Sarasota Bay, Charlotte Harbor, Albermarle-Pamlico Sound, Delaware Inland Bays, New York-New Jersey Harbor, and Long Island Sound have identified air deposition as a significant source of nitrogen to their estuary.¹⁵

¹² Deposition of Air Pollutants to the Great Waters: 3rd report to Congress. US EPA. 2000.

¹³ Frequently Asked Questions about Air Deposition: A Handbook for Watershed Managers. US EPA. 2001.

¹⁴ The Great Lakes: An Environmental Atlas and Resource Book. ("Great Lakes Atlas") 1995. Government of Canada and the United States Environmental Protection Agency. <http://www.epa.gov/glnpo/atlas/glat-ch4.html>

¹⁵ National Estuary Program: Air Pollution and Water Quality. US EPA. Valigura et al., 1996, as cited in National Estuary Program: Air Pollution and Water Quality. US EPA. <http://www.epa.gov/owow/test/estuaries/airdep.htm>

Table 1. Amount and Percentage of Nitrogen Entering the System Due to Atmospheric Deposition.¹

Bay or Estuary	Nitrogen (MM tons)	% of Total Nitrogen
Albemarle-Pamlico Sounds	9	38-44
Chesapeake Bay	45	27-38
Delaware Bay	8	15
Delaware Inland Bays*	-	21
Long Island Bay	12	20
Massachusetts Bays*	-	5-27
Narragansett Bay*	0.6	12
Sarasota Bay*	-	2
Tampa Bay*	1.1	28

* Indicates measurement of direct deposition to water surface only.

Because of the long water residency time in estuaries, nitrogen deposition and the resultant eutrophication are of major concern along the coast. The table below estimates nitrogen inputs to various estuaries from atmospheric deposition.

Traditional, non-point sources of nitrogen such as stormwater runoff and fertilizer use plus point sources of nitrogen from wastewater treatment plants must be added to atmospherically-deposited nitrogen entering the to gain a full appreciation of the nitrogen loadings occurring along the coasts. The results of these loadings are poor water clarity, low levels of dissolved oxygen, and harmful or toxic algal blooms. These water quality concerns impact the economic, cultural, and living resources of the estuary. On the average, atmospheric deposition is responsible for approximately 25% of the nitrogen loading to most of the East and Gulf Coast estuaries studied.¹⁶

B. Coastal Zone

Section 112(m) of the 1990 Clean Air Act (CAA), mandated the U.S. Environmental Protection Agency (EPA), in cooperation with the National Oceanic and Atmospheric Administration (NOAA), to identify and assess the extent of atmospheric deposition of air pollutants to the Great Lakes, the Chesapeake Bay, Lake Champlain, and coastal waters, collectively known as the Great Waters. The importance of atmospheric deposition from adjacent

Great Waters Pollutants of Concern
Cadmium and cadmium compounds
Chlordane
DDT/DDE
Dieldrin
Hexachlorobenzene
- Hexachlorocyclohexane
Lindane ((- hexachlorocyclohexane)
Lead and lead compounds
Mercury and mercury compounds
Polychlorinated biphenyls
Polycyclic organic matter
Tetrachlorodibenzo-p-dioxin (dioxins)
Tetrachlorodibenzofuran (furans)
Toxaphene
Nitrogen compounds

Source: *Deposition of Air Pollutants to the Great Waters: 3rd report to Congress.*

¹⁶ National Estuary Program: Air Pollution and Water Quality. US EPA. <http://www.epa.gov/owow/test/estuaries/airdep.htm>

urban areas in these Great Waters was recognized only in the 1990s as the first studies quantifying the loadings to Lake Michigan and Chesapeake Bay were performed under the Atmospheric Exchange over Land and Oceans Study (AEOLOS).

II. CONTAMINANTS OF GREATEST CONCERN

In the report, "Deposition of Air Pollutants to the Great Waters – Third Report to Congress", the EPA identifies 15 Pollutants of Concern (POC). These POCs were identified because they lend themselves to atmospheric deposition and at certain levels they are associated with adverse effects on organs in humans and animals. These effects impact the liver, kidney, nervous system, endocrine system, reproductive organs and immunological system. Additionally, there is evidence suggests that some of these pollutants are endocrine disrupters, interfering with the actions of hormones in humans and wildlife.¹⁷ The table below lists the 15 POCs.

Some of these pollutants occur naturally, such as nitrogen, sulfur, mercury, lead, cadmium, copper and zinc and others are manmade. In the case of the naturally occurring POCs, the anthropogenic sources of these pollutants often exceed emissions from natural sources.¹⁸

A. Nitrogen Compounds

Nitrogen is naturally occurring and essential to all life on Earth. Anthropogenic sources of nitrogen compounds currently equals natural sources and the largest source of nitrogen compounds to the atmosphere is the burning of fossil fuels.¹⁹ In addition to the burning of fossil fuels, agricultural activities such as fertilizer application and animal feedlots and waste lagoons also contribute to anthropogenic nitrogen compound inputs. Natural sources of nitrogen emissions include lightning; natural burns from forest fires or the like, and microbial activity.²⁰

The primary issue with nitrogen is the potential for eutrophication when excessive quantities are deposited into water. Eutrophication is defined as the unhealthy growth of phytoplankton in waterbodies. Several water quality problems arise from eutrophication such as decreased water clarity, low oxygen (hypoxia), loss of seagrass beds, changes in species composition and possibly increased harmful algal blooms.²¹

Acidification is another problem associated with nitrogen compounds. Airborne nitrogen and sulfur gases (NO_x and SO_x) react with water, oxygen, and other compounds to form sulfuric acid and nitric acid. NO_x and SO_x can reach a waterbody through dry deposition, combining with the surface water,

¹⁷ Deposition of Air Pollutants to the Great Waters: 3rd report to Congress. US EPA. 2000.

¹⁸ Frequently Asked Questions about Air Deposition: A Handbook for Watershed Managers. US EPA. 2001.

¹⁹ Schlesinger, 1997, as cited in Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

²⁰ Frequently Asked Questions about Air Deposition: A Handbook for Watershed Managers. US EPA. 2001.

²¹ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

wet deposition, falling to the earth as snow, fog, or acid rain, or as indirect deposition. In general, acidified water bodies have decreased number and types of plants and animals. Severe acidification of a waterbody can result in major kill offs of native species, replacing them with a few species that can tolerate the conditions.²²

Waterbodies that have become eutrophied or acidified have direct and indirect effects on the surrounding biodiversity. The direct impacts on the plants and animals that exist in the ecosystem are easy to deduce. Indirect impacts are less obvious though. Migratory birds rely on water resources for their food and the trickle-down effect of excessive nitrogen loading leads to reduced populations. Indirect impacts also affect humans. Eutrophied waterbodies have significant economic impacts, as the costs of fixing the ecosystem are oftentimes excessive. If the eutrophied water is a drinking source, its taste, odor and color will be impacted.²³ Algal mats formed from the eutrophication, impede boat traffic and can cause large-scale fish kills. Toxic algal blooms destroy fish and shellfish populations and have been found to harm tourism.²⁴

B. Mercury

Mercury is a toxic metal occurring naturally and through man-made processes. Anthropogenic activities have greatly increased the concentration mercury in the environment. It is estimated that man-made emissions of mercury have tripled concentrations in the air and in the surface of the ocean since 1900.²⁵ Human activities presently account for about 75% of worldwide mercury emissions. Man-made sources include incinerators, coal-burning facilities, certain industrial processes, and household items. Coal-burning facilities and incinerators release mercury by burning material that contains mercury. Older methods of manufacturing chlor-alkali products (such as chlorine and caustic soda) use mercury and result in its release to the atmosphere. Finally, a number of consumer products also contain mercury including batteries, fluorescent lights, thermometers, electrical switches, dental fillings, and antibiotic treatments such as Thimerosal and mercurochrome.

Atmospheric deposition plays a major role in delivering mercury to ecosystems. Up to 83% of the mercury load to the Great Lakes comes from atmospheric deposition.²⁶ Approximately half of the mercury in Chesapeake Bay is deposited from the atmosphere directly to the surface of the bay.²⁷

²² What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

²³ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

²⁴ National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment on the Nation's Estuaries. NOAA. 1999.

²⁵ Mason et al. 1994, as cited in Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

²⁶ Shannon and Voldner, 1995, as cited in Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

²⁷ Mason et al., 1997, as cited in Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

The National Atmospheric Deposition Program (NADP) estimated that mercury was deposited at the rate of 4-20 micrograms per square meter in the United States in 1998.²⁸

Because of its unique chemical characteristics; it can travel great distances in the atmosphere. Also, biological processes can transform mercury into a very toxic compound known as methyl mercury. This compound is considered bioaccumulative, meaning it can accumulate in the tissues of fish and shellfish to concentrations much higher than the surrounding environment and can pose a threat to the health of humans and wildlife.²⁹

The primary health effects from mercury are on the development of the brain and nervous system. Exposure to high mercury concentrations over a long period of time can result in brain damage. Mercury is also dangerous to developing fetuses, children, and people that eat unusually large amounts of fish.³⁰

C. Other Metals

Other metals listed as POCs include lead and cadmium. These other metals have seen their environmental concentrations increase through increased industrial processes. While they are naturally occurring in the environment, elevated levels can have toxic effects on humans and wildlife.³¹

Lead contamination results from the burning of gasoline additives and the incinerating of material that contains the metal, such as solder and paint. Cadmium pollution also arises from incinerating cadmium-containing waste such as batteries and electroplating solder. Cadmium is also a significant by-product of zinc purification. Sources of cadmium include incinerators, smelters, and coal-burning facilities.³²

Lead is particularly harmful to children and developing fetuses. Symptoms include impaired mental and physical development, impaired academic performance, hearing loss, joint and muscle pain, reproductive problems, and deficits in motor skills. While cadmium does not affect the brain or developing fetuses, exposure can result in kidney damage, high blood pressure, bone and joint pain, and may depress immune functions.³³

²⁸ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

²⁹ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

³⁰ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

³¹ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

³² Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

³³ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

D. Pesticides

There are tens of thousands of registered pesticides used in the United States and the majority of them are synthetic. After they are released into the environment, the pesticides breakdown via chemical reactions into byproduct chemical compounds. Some byproducts are toxic others are non-toxic. Many pesticides break down very slowly and therefore the pesticide and its byproducts can remain in soil, air, or water for decades. ³⁴

A major source of pesticides to waterbodies is atmospheric. The possibility that the air will deposit any one pesticide depends on a variety of factors such as the pesticides use, chemical characteristics, quantity already existing in the receiving water body, and the pathway in which it reaches the water body. There is a seasonality component to pesticide concentrations in waterbodies too. The summer traditionally sees the peak pesticide loading of waterbodies through atmospheric deposition.³⁵

The table below lists the pesticides that are considered POCs, their history and uses and effects.

Pesticide	History/Uses	Effects
Chlordane	1948 to 1978 widely used pesticide. Phased out 1983 to 1988. Used to termite proof many homes. Still manufactured and exported to other countries for use as pesticide.	Persistent toxin that remains in food and water supply. Cancer causing. Harms endocrine system, nervous system, digestive system, and liver.
DDT/DDE	Used as pesticide until banned in 1972. Highly persistent in environment. Fish consumption advisories for DDT still exist in Great Lakes. Still used as pesticide and in disease control programs in other countries.	Can cause liver cancer, damages nervous system, damages reproductive system
Aldrin/Dieldrin	Popular pesticide 1950-1970. Restricted in 1974, banned completely in 1987. Dieldrin persists today at very low levels in nearly all environments. May concentrate in shellfish, dairy products or in soils around houses treated for termites before 1987.	May build up in body tissues. Affects central nervous system. Exposure results in headaches, convulsions, and suppressed immune system. High doses can cause death.

³⁴ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

³⁵ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

Hexachlorobenzene	Popular fungicide until 1965. Extremely stable in the environment and can build up in fish, birds, mammals and lichens. Present as waste product in chlor-alkali plants. Can enter atmosphere through incineration.	Can damage liver, thyroid, nervous system, kidneys, bones, and blood. Can result in abnormal fetal development and is especially toxic to young children.
a-Hexachlorocyclohexane (several related compounds including Lindane)	Used as insecticide on fruit and vegetable crops, and forest products. Still used to control lice and scabies. Not produced in U.S. since 1977, but still imported and used here. Extremely volatile, found in rainwater. Broken down by microbes in soils and water. Generally persists less than 30 days.	Affects reproductive system and immune system at low levels. May cause seizures, blood disorders and death at high levels.
Toxaphene	Volatile mixture of 670 chemicals. Used heavily as insecticide in Southern U.S. until 1990. Still used on pineapples in Puerto Rico and bananas in Virgin Islands.	Highly persistent in the environment. May accumulate in fish or mammals. Affects liver, kidneys, adrenal gland and immune system at low levels. Can damage lungs and nervous system or cause death at higher levels.

Source: Which Atmospheric Deposition Pollutants Pose the Greatest Problems for Water Quality?

E. Combustion Emissions

The incineration of waste releases pollutants known as combustion emissions. These pollutants include dioxins, furans, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). They degrade slowly in the environment and have been determined to build up in tissues of humans and wildlife. They pose significant threats to human and ecosystem health.

Dioxins and furans are groups of chemicals that occur as byproducts of industrial processes. They have no use as products. Both groups enter the atmosphere predominantly during incineration and are capable of becoming deposited in waterbodies. In particular, dioxins are very stable and may travel great distances in the atmosphere.³⁶

TCDD or 2,3,7,8-tetrachlorodibenzo-p-dioxin is the most toxic dioxin compound. Exposure to significant levels of TCDD causes a severe skin disorder known as chloracne and long-term exposure to low levels can also cause changes in human hormone levels. TCDD has been shown to disrupt the endocrine system, weaken immune systems, and cause reproductive damage to wildlife populations. Similarly, the most toxic furan is a compound known as 2,3,7,8-tetrachlorodibenzofuran or TCDF. Human exposure to high levels of TCDF can result in eye and skin diseases, damage to the nervous system, and impairments to developing fetuses. Furans have been determined to cause damage to

³⁶ Which Atmospheric Deposition Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

the stomach, liver, kidneys, and immune system in animals. Both groups of compounds are persistent in the environment and can bioaccumulate in the tissue of fish and other animals. Typical human exposure of dioxins and furans has resulted from eating foods contaminated with either of these chemicals.³⁷

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals comprised of over 100 compounds. They have been determined to arise from the incomplete combustion of fuel, garbage, coal, and other materials and often occur in complex mixtures such as soot. Soil microorganisms can break down most PAHs over a period of weeks or months. Traditional exposure occurs by breathing smoke or exhaust from automobiles or other combustion processes. They tend to cause breathing difficulties and are assumed to be carcinogenic³⁸

Polychlorinated biphenyls (PCBs) include coolants and lubricants produced for industrial purposes until they were phased out in 1977. These chemicals are highly persistent and can still be found in older electrical equipment and waste sites. PCBs primary means of introduction to the environment today is through incineration of material that contains them.³⁹

PCBs are stable and have been researched to concentrate in the tissues of aquatic animals. In some cases, concentrations of PCBs in the tissue animals can exceed hundreds of thousands of times that of the surrounding water. PCBs cause bronchitis, irritation of the gastrointestinal tract, nervous system impairment, fertility problems, and changes in liver function. Additionally, they have been shown to cause cancer in lab animals, and are a suspected human carcinogen.⁴⁰

III. ISSUES

A. Sources

In response to the realization that a consistent and complete inventory of toxic emissions was not available the Great Lakes Commission established a "Great Lakes Regional Air Toxic Emissions Inventory⁴¹." This organization is charged with identifying protocols⁴² and procedures for constructing an emissions inventory for all the Great Lakes.

Unfortunately there does not appear to be a corresponding inventory for those states outside the Great Lakes. This is problematic because there is evidence that a portion of the toxics deposited in

³⁷ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

³⁸ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

³⁹ Which *Atmospheric Deposition* Pollutants Pose the Greatest Problems for Water Quality? US EPA. <http://www.epa.gov/owow/oceans/airdep/air2.html>

⁴⁰ What are the Major Effects of Common Atmospheric Pollutants on Water Quality, Ecosystems, and Human Health? US EPA. <http://www.epa.gov/owow/oceans/airdep/air3.html>

⁴¹ Great Lakes Regional Air Toxic Emissions Inventory, <http://www.glc.org/air/>

⁴² Air Toxics Emissions Inventory Protocol for the Great Lakes States, <http://www.glc.org/air/protocol/prototoc.html>

the Great Lakes and its watersheds originates from sources outside the region. Consequently, depending on estimates from the Fate and Transport section (below) there may be a need to consider a far larger spatial distribution of toxic emissions. Toxaphene, for example, has been shown to be associated with transport from source regions in the southern United States.

B. Fate and transport

1. What is Known

As illustrated earlier the atmosphere has a remarkable capacity to redistribute all materials emitted into it. Our capacity to reconstruct either the flow of materials from their source or the probability of influence of upwind source to a given measurement depends on the use of a combination of observations and modeling. The wind observations needed are less the numerous surface based point measurements than it is the non-surface measurements. The observations normally available are from the NOAA network of upper-air rawinsonde observations. Observations from this network, made semi-daily at locations located about 400 km apart, are interpolated to estimate wind flow at intermediate places and times and are used to initialize models that use representations of the underlying surface to reproduce wind patterns in a higher resolution and with better physical realism.

It is also understood that the dynamics of mixing in the Great Lakes regions are highly influenced by the inhomogeneity of the Great Lakes region, particularly in the lake shoreline region. Under conditions where the lake is colder than the air above it, the air will stratify and little vertical redistribution will occur over the lake itself. However, once the plumes reach the downwind shoreline the heat of the land produces relatively rapid mixing of pollutants to the ground. In principle, this process would enhance the availability of toxics to the shoreline environment and reduce direct lake surface deposition. On the other hand, when the air is colder than the underlying water as often happens in late Fall and winter leading to lake effect storms, rapid mixing is possible over the lake and just downwind.

2. What are the Significant Unknowns

As toxic deposition is a problem of the integration of days into a mass loading the details of air transport at any one-day or less may not be critical to assessing the problem. However, the degree to which we will need to isolate days because of unique chemical processes will dictate the importance of modeling and measurement at high resolutions. The policy questions that need to be answered through modeling include (Delta Institute, 2001):

- What level of air emission reduction from regional sources must be achieved to meet water quality and public health goals and is this possible with current regulations?
- What are the source types and regions (source-receptor relationships) of deposited pollutants?
- How much of the air toxics problem is from sources outside the region and

- What will be the impact on the region from national and international policy programs?
- What is the importance of atmospheric deposition relative to other sources?

These questions can be addressed through a combination of measurement and modeling.

C. Deposition

1. What is Known

Dry particle deposition is broadly defined as the transport of particles and the contaminants associated with them onto surfaces. In general, the amount of contaminants deposited depends on concentrations in the air mass. The relationship is complex, however, depending on such physical factors as wind speed, the area of the receiving surface and whether that surface is water or land, and the properties of the contaminant, such as reactivity and the size of the particle with which it is associated.

Although progress has been made in recent years in understanding dry deposition, there are no universally accepted methods to directly measure or calculate dry deposition. Commonly, dry deposition to water bodies is estimated using measured airborne particle concentrations, and a modeled or estimated dry deposition velocity.

Wet deposition refers to the incorporation of both gases and particles into all types of precipitation: rain, fog or snow. Pollutants may be removed from air by wet deposition through three main mechanisms:

1. Small particles can serve as cloud condensation nuclei and become entrapped in raindrops;
2. Particles can be incorporated into falling raindrops by a variety of mechanisms depending on their size, referred to as particle scavenging;
3. Gaseous pollutants can be dissolved into cloud droplets and falling rain or snow.

Trace metals and semi-volatile organic chemicals (chemicals that can exist either as a gas or associated with particles) can become associated with rain either by being dissolved in the raindrop or by being incorporated as particles. From an ecological perspective, the dissolved form is of greatest interest because it may be more readily available for bioconcentration in tissues.

Measurements of most pollutants of concern have been performed only since the late 1980s. For mercury, the first reliable data in Michigan was collected in the 1990s and the first network of Hg measurements was established as part of the Lake Michigan Mass Balance Study (LMMBS) carried out from 1994-1995. A significant gradient in the deposition of mercury has been reported with the highest deposition reported in the southern part of the state. Event precipitation measurements have been performed at sites in Dexter and Pellston, MI since 1994. These measurements do not indicate statistically significant trends in the deposition of mercury but the south-north gradient in the deposition is still apparent.

2. What are the Significant Unknowns

The rate of removal by wet deposition depends on properties of the pollutants - solubility, vapor pressure, and the size of the particles - as well as on properties of the rain - the size of the raindrops and intensity of the rainfall. Although it is the easiest of the three depositional processes to measure, many scientific uncertainties about the wet deposition process remain, such as the process of incorporation of particles into precipitation droplets and the role of particle size.

D. Persistent Bioaccumulative Toxic (PBT) Pollutant

1. What is Known

The Persistent Bioaccumulative Toxic (PBT) Pollutants include mercury, PCBs, dioxins and furans, toxaphene, aldrin/dieldren, benzo(a)pyrene, chlordane, DDT, hexachlorobenzene and alkyl lead. Monitoring for these PBTs only began in the 1990s with programs in the US and Canada being initiated under joint bi-lateral agreements. Compounds such as dioxins and furans have recently been added to the monitoring programs and the data is expected to be available at the end of 2002.

2. What are the Significant Unknowns

While programs are under way to address the emissions of the PBTs to the atmosphere and to quantify air deposition, many of these efforts are not fully implemented at present and therefore the regulatory community is unable to assess the risks to health and the environment. In addition, the modeling tools are not yet developed which allow one to establish source-receptor relationships for most of the PBTs and then to the health effects. Particularly unclear at this time is the process-level understanding of how some of the PBTs transform in different ecosystems and how this affects the bioaccumulation of the pollutants up the food chain. Since neither the monitoring data or the modeling tools are adequate at this time there are significant uncertainties in the current risk assessments performed by the agencies.

E. Runoff

1. What is Known

The task of identifying the causes of water quality problems in urban watersheds presents many obstacles because of the multitude of potential sources and land-use activities.

2. What are the Significant Unknowns

F. Effects

1. Aquatic chemistry and ecosystem processing

Certain contaminants have clear and indisputable impacts on the waters they reach. For example, there is no doubt that nitrogen and phosphorous loadings into the Great Lakes results in eutrophication (i.e. increased biological growth), which in turn decreases the amount of oxygen available for aquatic life. There is also no doubt that sulfur dioxide emissions from industrial smoke stacks cause acid rain. However, it becomes difficult to isolate the cause and effect relationship of any one pollutant due to the fact that organisms are often exposed to many environmental chemicals as well as general ecological disturbances. Laboratory experiments that focus on the impacts of a potential carcinogenic chemical cannot capture the synergistic impacts that occur when this chemical combines with others in nature.⁴³ More often than not, an ecosystem is subject to contamination by a host of pollutants, not just one. Additionally, lab experiments cannot replicate ecological change. For example, the biological communities in the Great Lakes have changed substantially over the last 100 years due to forces such as exotic species, pollution, fishing, development of shorelines, and hydrological changes.⁴⁴ Laboratory work cannot mirror or predict such change.

In assessing the impact of non-point source pollution on humans, it is similarly difficult to pinpoint the exact cause of certain health effects. For example, if sperm counts are indeed declining, is this due to one particular chemical or multiple chemicals? While there are studies which show that exposure to certain endocrine disrupters has a negative impact on human reproductive systems, there is a need for studies that quantify the risks of exposure over an individual's lifetime from conception to adulthood.⁴⁵ Such studies could begin to shed light on whether genetic or environmental factors play the larger role in such health concerns.

In general, when organic contaminants hit the surface of the Great Lakes, they do not readily dissolve or form chemical bonds with water molecules. Rather, they adhere to any fine, electrically charged particles in the water. These particles, which are microscopic in size and are derived from erosion of rock and soils, eventually sink to the bottom. The fate of these particles then depends on water currents or human activities (for example dredging). Such movement and activity determines if these contaminated particles are moved elsewhere or buried underneath other settling particles.⁴⁶

As these particles descend down a lake's water column, or as they lie on the lake floor, animals actively feed on these particles, digesting the attached contaminants as well. Contaminant exposure is particularly high for benthic, or bottom-dwelling organisms. Not only do these pollutants enter the organisms' bodies via ingestion, they also enter through absorption across the animals' skin. These pollutants build up within an organism, and get passed on when a

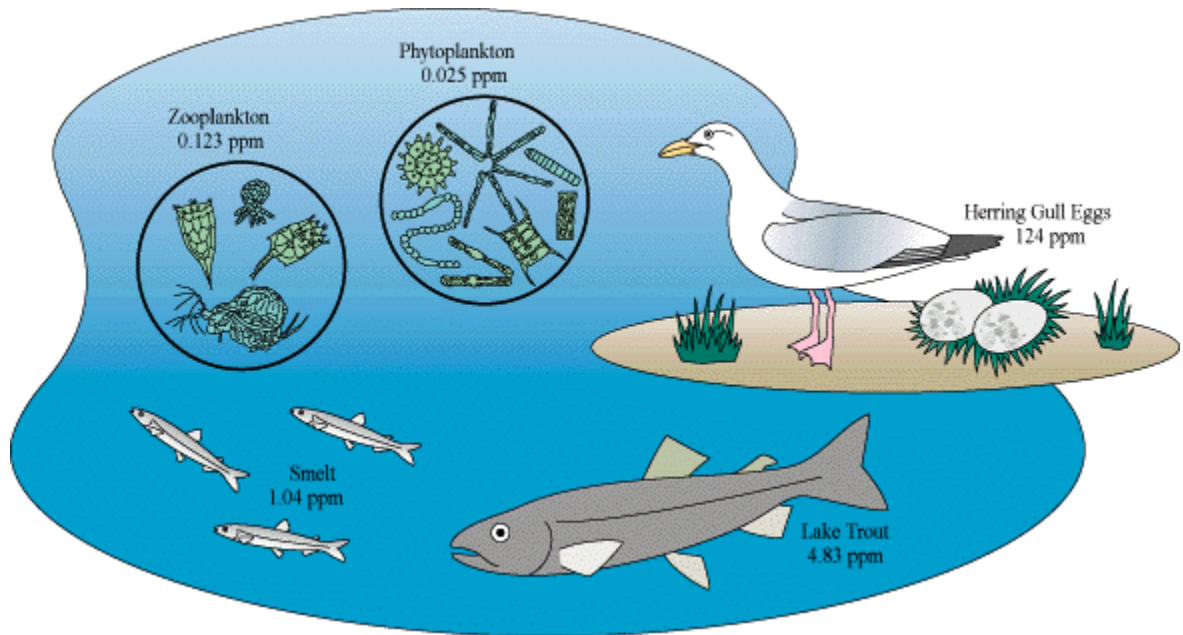
⁴³ Committee on Hormonally Active Agents in the Environment. National Research Council. 2000.

⁴⁴ National Research Council, 2000.

⁴⁵ National Research Council, 2000.

⁴⁶ Waterborne Contaminants in the Great Lakes. Great Lakes Environmental Research Laboratory. <http://www.glerl.noaa.gov/pubs/brochures/wcontflyer/wcont.html>

predator eats the organism. This begins the process of biomagnification, whereby each higher level up the food chain has a diet increasingly rich in contaminants. At the top of the food chain, fish-eating birds and mammals are exposed to high levels of contaminants. Humans are also impacted through the consumption of fish.⁴⁷ Below is a diagram which shows the degree of concentration in each level of the Great Lakes aquatic food chain for PCBs in parts per million. The highest levels are reached in the eggs of fish-eating birds such as herring gulls.⁴⁸



Source: The Great Lakes: An Environmental Atlas and Resource Book.

The processes of bioaccumulation and biomagnification depend in part on the chemical nature of the pollutant. For example, mercury transfers efficiently up the aquatic food chain, eventually bioaccumulating in the predators at the top. However, inorganic mercury is less efficiently absorbed and is more readily eliminated from the body than methylmercury. It therefore does not tend to bioaccumulate as does methylmercury.⁴⁹

2. Ecosystem Health

Toxic contamination of the environment has been a result of the increased production and use of synthetic organic chemicals and metals since the 1940s. The dangers of toxic chemicals were

⁴⁷ Great Lakes Environmental Research Laboratory

⁴⁸ The Great Lakes: An Environmental Atlas and Resource Book. ("Great Lakes Atlas") 1995. Government of Canada and the United States Environmental Protection Agency. <http://www.on.ec.gc.ca/great-lakes-atlas/glat-chap4-e.html#7>

⁴⁹ U.S. EPA, 1997, as cited in Delta Institute.

first demonstrated through the study of the effects, persistence and movement of the pesticide DDT.⁵⁰ In 1962, Rachel Carson's book *Silent Spring* warned of the dangers of indiscriminate use of DDT. The first bans of DDT in the Great Lakes states occurred after a 1968 hearing that called attention to the link between its use and the disappearance of eagles. A national ban on most uses of DDT went into effect in 1972.⁵¹

The specific link between atmospheric deposition and ecological damage emerged in the 1970s, as one study demonstrated that the atmosphere was a significant source of phosphorus entering Lake Michigan. In 1975, PCBs were found in lake trout in inland lakes on remote Isle Royale. A 1980 study showed that atmospheric deposition was the source of toxaphene – a pesticide widely used in the South and far West – found in Isle Royale fish.⁵²

National Research Council Findings

In 2000, the National Research Council formed an expert committee to investigate the hypothesis that toxic contamination – specifically endocrine disruptors – has deleterious effects on the health of wildlife. This committee examined laboratory experiments and field observations of wildlife to come up with findings with respect to developmental, reproductive, neurologic, immunologic, carcinogenic, and ecologic effects of endocrine disruptors. While many of these studies look specifically at the impact of point-source discharge (e.g. effluent from paper mills), it is reasonable to assume that contaminants cause the same health problems regardless of how they entered a body of water. Below is a summary of the findings for each of these effects.

Developmental and reproductive effects

Wildlife studies show associations between reproductive and developmental anomalies and exposure to environmental contaminants, some of which are hormonally active agents (HAAs).

Effects include intersexes in trout, increased egg and fry mortality in trout and salmon, thyroid enlargement in salmon, and delayed sexual maturity in white suckers. Dioxin has been shown to induce blue-sac disease in developing trout and growth and survival reduction in salmon. And DDT has been implicated in abnormal testes in male and abnormal ovaries in female alligators from Lake Apopka, Florida.⁵³

Neurological effects

While the NRC listed no field studies, the authors did cite laboratory experiments that demonstrated that monkeys exposed to PCBs in utero and during lactation have deficits in cognitive function soon after exposure.⁵⁴

⁵⁰ Great Lakes Atlas

⁵¹ Dunlap, 1982 as cited in Delta Institute

⁵² Delta Institute

⁵³ National Research Council, 2000.

⁵⁴ National Research Council, 2000.

Immunologic effects

There is evidence of suppression of the immune system by exposure to organochlorines in birds of the Great Lakes region. There is also indication that PCB tainted fish from the Baltic Sea are the cause of suppressed innate and acquired immune responses in seals.⁵⁵

Carcinogenic effects

While certain endocrine disrupters (e.g. toxaphene, DDT, endrin) have been associated with tumors of the thyroid, pituitary or renal glands in particular species of lab animals, endocrine disrupters in general have not been shown to induce tumors in reproductive or other endocrine organs after postnatal exposure.⁵⁶

It is probable that endocrine disrupters have contributed to declines in certain wildlife populations (e.g. fish and birds of the Great Lakes and juvenile alligators of Lake Apopka). These contaminants are likely to be a factor in diseases and deformities in minks in the U.S., river otters in Europe, and marine mammals in European waters. It is hypothesized that such contaminants play a role in the poor reproductive success of the Florida panther and the increased embryonic mortality of the snapping turtle in the Great Lakes.⁵⁷ It is also suspected that up to 30 percent of the loons in the northeastern U.S. have mercury levels high enough to cause adverse affects.⁵⁸

3. Human Health

Perhaps the first recognition of the human health dangers of toxic contaminants in the Great Lakes region came in a report by Royal Society of Canada and National Research Council in 1985.⁵⁹ The 1989 presentation of *Great Lakes, Great Legacy?* to the IJC documented the threats of toxics to humans and helped fuel increased activism for toxics regulation.⁶⁰ And in 1999, the National Research Council reported in the growing scientific evidence that certain organic chemicals are "hormonally active" and may be impacting the endocrine systems of humans.⁶¹

Fish consumption is the predominant pathway of human exposure to many toxic pollutants – especially mercury, dioxins and PCBs. For the general population, exposures to such chemicals may not pose a significant risk, however certain groups such as young children, pregnant women and their developing fetuses, and subsistence fish-eating populations face above-average risk.

⁵⁵National Research Council, 2000.

⁵⁶ National Research Council, 2000

⁵⁷ National Research Council, 2000

⁵⁸ Deposition of Air Pollutants to the Great Waters: 3rd report to Congress. US EPA. 2000.

⁵⁹ Delta Institute

⁶⁰ Colburn et al., 1990, as cited in Delta Institute

⁶¹ National Research Council, 2000 as cited in Delta Institute

Similarly at risk are those persons who consume above-average amounts of fish from the Great Lakes. The human health impacts of such consumption are expounded upon below.

Developmental and reproductive effects

Adverse reproductive and developmental effects have been observed in humans as a consequence to exposures to endocrine disrupters. The effects of prenatal exposure to toxics such as PCBs and DDE have been studied in several populations in the U.S. and abroad, and these studies indicate that such exposure can result in lower birth weight and shorter gestation. Exposure is also correlated with deficits in IQ and memory as well as delayed neuromuscular development.⁶² Mercury is also implicated in developmental problems in children exposed through prenatal consumption of contaminated fish.⁶³

The National Research Council asserts that reported increases in the incidence of male reproductive disorders, testicular cancer, and lower sperm counts cannot be definitively linked to HAAs at this time.⁶⁴

Neurological effects

The results of cognitive and neurobehavioral studies of mother-infant cohorts exposed to certain toxics (e.g. PCBs, dioxin) by accident or through fish consumption provide evidence that prenatal exposure to these toxics can affect the developing nervous system.⁶⁵ Both mercury and toxaphene have also been linked to neurological damage.⁶⁶

Immunologic effects

The National Research Council reports that insufficient evidence exists to link endocrine disrupters with impaired human immune systems.⁶⁷

Carcinogenic effects

As is the case with wildlife, there are few studies that assess the carcinogenic effect of prenatal exposure to HAAs. Certain toxics (e.g. toxaphene, DDT, endrin) have been associated with tumors of the thyroid, pituitary or renal glands in particular laboratory species, though HAAs in general have not been shown to induce tumors in post-natal exposure. An evaluation of existing studies conducted through the year 2000 does not support a link between adult exposure to DDT, DDE, TCDD and PCBs and breast cancer. These studies also do not support associations between these toxics and other cancers such as testicular, prostate and endometrial. Few of these studies however have examined measured concentrations of these compounds in adults in

⁶² National Research Council, 2000

⁶³ ATSDR, 1999 as cited in Delta Institute

⁶⁴ National Research Council, 2000

⁶⁵ National Research Council, 2000

⁶⁶ ATSDR, 1999 as cited in Delta Institute

⁶⁷ National Research Council, 2000

relation to cancer risk. A recent study reported a link between dieldrin and breast cancer, though more epidemiological and laboratory experiment are needed to help confirm or refute this possible link.⁶⁸

4. Human Use Effects

In an effort to clean up the most polluted waters of the Great Lakes basin, the United States and Canada, under the auspices of the Great Lakes Water Quality Agreement, committed to work with state and provincial governments in developing and implementing Remedial Action Plans (RAPs) for designated Areas of Concern (AOCs). These AOCs include rivers, lakes and bays where one or more of 14 beneficial uses have been impaired due to past or current pollution. Historic pollution of these sites typically came from direct release from local industry, however runoff, reemission and revolatilization of pollutants are also at work.

G. Regulatory Actions

1. Challenges of multimedia, cross-program, transboundary non-point source pollution management

By its very definition, non-point source pollution (NPS) is a difficult phenomenon to get a handle on from a policy perspective. The EPA defines NPS as "any source of water pollution that does not meet the legal definition of "point source" in section 502 (14) of the Clean Water Act." A point source is defined as any "discernible, confined and discrete conveyance."⁶⁹ These indiscernible or indiscrete loadings might come from pesticide runoff from a local farm, nitrogen oxide emissions from a coal-fired power plant hundreds of miles away, or from mercury emissions from an industrial complex in a country thousands of miles away. Given this global interdependency, any regulatory framework that addresses pollution on a state or nation basis will have limited success. For example, the U.S. Clean Air Act and other regulations have been successful in reducing certain pollutants such as lead and dioxin, yet these laws cannot impact the amount of such contaminants transported through the atmosphere from other nations. Over the last decade or so however, there has been greater cooperation on a regional and global basis. In 1997, the US and Canada signed the Binational Toxics Strategy, with a goal of virtual elimination of a dozen priority pollutants.⁷⁰ On a global scale, the United Nations Environment Program led an effort to address persistent organic pollutants (POPs) on a global basis.

The multimedia aspect of NPS pollution also presents a coordination challenge to regulatory bodies, since the US EPA and many state departments of environmental protection have separate divisions for air, water and land – each division with its own bureaucratic inertia and nuances. Thus, coordinating policy and regulation can be difficult. There are however examples of federal coordination on policy decisions. The Clean Water Action Plan of February 1998 is an interagency and multimedia strategy to address the remaining obstacles to the original goal of the Clean

⁶⁸ National Research Council, 2000

⁶⁹ Background paper on Nonpoint Source Pollution, US EPA Office of Water Quality

⁷⁰ Deposition of air Pollutants to the Great Waters: 3rd report to Congress. US EPA. 2000.

Water Act – to make all bodies of water fishable and swimmable.⁷¹ Another example is the so-called “cluster rule” for the pulp and paper industry, which was the first attempt to integrate, coordinate and streamline requirements of the Clean Water Act and Clean Air Act.⁷²

It can also quite difficult to isolate the exact source of particular pollutants, since such pollutants can cycle continuously through various media depending on their chemical makeup and general ecological and atmospheric conditions. Therefore, a pesticide that is sprayed on a field might be transported through the atmosphere to a second field hundreds of miles away, and then might carried by rainwater to a river for ultimate deposition in a lake. Without knowing the origin of a particular contaminant, regulatory bodies may be unduly focusing their policy efforts on the tail end of the system instead of intervening at a higher leverage point.

Generic management objectives and alternatives of U.S. policy

In the 1970s and early 1980s, the primary objectives of U.S. federal regulation were identification and reduction of point source pollution. For example, the Clean Air Act (1969) focused on reducing criteria air pollutants from point sources, while the Clean Water Act (1972) emphasized reduction of direct of “end of pipe” discharges.⁷³ This focus on localized sources began to change in the late 70s and early 80s due to several studies that demonstrated the role of atmospheric deposition in local water pollution. In 1975, PCBs were discovered in lake trout in an interior lake on Isle Royale – a remote island in northern Lake Superior.⁷⁴ A 1977 study revealed significant loadings of phosphorous by air deposition into Lake Michigan.⁷⁵ And in 1980, toxaphene – a pesticide mainly used in the deep South and far West – was found in fish on Isle Royale.⁷⁶ These research efforts and others showed that atmospheric deposition was a significant source of Great Lakes pollution, and helped change the focus of federal policy to include non-point source pollution. Below is list of the primary U.S. federal policy tools that address atmospheric deposition.

Great Lakes Water Quality Agreement

A pact between the U.S. and Canada signed in 1972 as an attempt to address phosphorous loadings, the Great Lakes Water Quality Agreement (GLWQA) calls for the virtual elimination of toxics of concern to the Great Lakes. The GLWQA is also the source of much of the research on atmospheric deposition to the Great Lakes. A 1987 annex requires the U.S. and Canadian governments to research, monitor and implement pollution control measures for the purpose of reducing atmospheric deposition of toxics contaminants, especially persistent bioaccumulative

⁷¹ US EPA. 2000.

⁷² US EPA. 2000.

⁷³ Atmospheric Deposition of Toxics to the Great Lakes: Integrating Science and Policy. The Delta Institute. 2000.

⁷⁴ Swain, 1978 as cited in The Delta Institute. 2000.

⁷⁵ Eisenreich et al., 1977 as cited in The Delta Institute. 2000.

⁷⁶ Hoff, 1996 as cited in The Delta Institute. 2000.

toxics (PBTs), to the Great Lakes basin.⁷⁷ This 1987 annex also established new management approaches, including Remedial Action Plans (RAPs) and Lakewide Management Plans (LaMPs), the former focused on 42 geographic Areas of Concern in the Great Lakes basin, and the latter designed to improve the environmental quality of the open waters of the Great Lakes.⁷⁸

Clean Air Act Amendments of 1990

In 1990, the Clean Air Act was amended to specifically address atmospheric deposition. Section 112(m) of the Act directs the U.S. EPA to safeguard public health and the environment from any air pollution that falls on the Great Lakes. These efforts include emissions inventories, modeling and mass balance studies that inform new laws and policies.⁷⁹ This amendment also requires the EPA, in cooperation with the National Oceanic Atmospheric Administration (NOAA), to periodically submit a report to Congress on atmospheric deposition to the Great Lakes.⁸⁰

The 1990 amendment also listed 189 hazardous air pollutants (HAPs), and engendered specific programs to address them. One program, Maximum Achievable Control Technology Standards, or MACT, is a technology-based approach to reduce HAP emissions from major sources (more than 10 tons per year of any one pollutant, and more than 25 tons per year of any combination of pollutants). MACT sets emission limits based on the best-performing facilities in a particular industry. Another program is Residual Risk, which requires the U.S. EPA to set stricter standards than MACT for sources of known, probable, or possible human carcinogens if lifetime risk of cancer exceeds one in a million.⁸¹

Clean Water Act amendments of 1987

Prior to 1987, the Clean Water Act (CWA) dealt only with point sources of pollution, and did so via National Pollutant Discharge Elimination System (NPDES) permit program. In 1987, Congress amended the Act to address non-point source pollution. Under this amendment, the EPA is authorized to issue grants to help states implement management programs.⁸²

The CWA also establishes Total Maximum Daily Load (TMDL), which is a critical regulatory tool in controlling both point and nonpoint source pollution. TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. This TMDL, which is allotted to specific sources, must include a margin of safety to ensure State-

⁷⁷ The Delta Institute. 2000.

⁷⁸ Water Pollution in the Great Lakes. June 2002. Great Lakes Information Network. <http://www.great-lakes.net/teach/pollution/water/water4.html>

⁷⁹ Atmospheric Deposition in the Great Lakes Region. Great Lakes Information Network (get year and URL)

⁸⁰ EPA 2000.

⁸¹ The Delta Institute. 2000.

⁸² Background paper on Non-point Source Pollution, US EPA Office of Water Quality

designated purposes such as drinking, recreation and fishing. States, Territories and Tribes set tMDLs.⁸³

Other U.S. regulation

There are a host of other regulatory bodies and regulations that deal either directly or indirectly with atmospheric deposition in the U.S. Several are listed below:

- NOAA administers the Coastal Zone Management Act, and conducts research on atmospheric deposition at 23 National Estuarine Research Reserve System (NERRS) sites.
- The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was enacted by the EPA to respond to releases of hazardous substances from waste disposal sites, including volatilization into air from sediment or surface sources.⁸⁴
- The Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 among other things established the Toxic Release Inventory, which requires manufacturing facilities to report their toxic emissions.
- The 1984 amendment of the Resource Conservation and Recovery Act (RCRA) set standards for the reduction or elimination of hazardous waste generation and treatment and disposal for existing hazardous waste. While primarily a land-based program, RCRA could play a role in controlling fugitive emissions.⁸⁵

2. Federal, state (Provincial) and local coordination

By one estimate, there are more than 60 programs in progress at the local, national, and international level that deal with issues of concern to the Great Waters.⁸⁶ With this number comes a great need for coordination in arriving at the ultimate goal of a cleaner and healthier Great Lakes basin. Over the last decade, there are numerous examples of coordination on both a national and an international basis.

Coordination at the federal level (U.S.)

Increasingly, the EPA is using cross-program teams and partnerships with other agencies to address complex, multi-media environmental concerns. One example listed above – the Clean Water Action Program – is a coordinated federal effort involving the EPA and the Departments of Defense, Agriculture, Interior, and Commerce, all of which have some jurisdiction over issues affecting the quality of the country's waters. This program came about because the EPA's

⁸³ [Introduction to TMDLs. U.S. EPA. http://www.epa.gov/owow/tmdl/intro.html \(October 28, 2002\)](http://www.epa.gov/owow/tmdl/intro.html)

⁸⁴ The Delta Institute. 2000.

⁸⁵ The Delta Institute. 2000.

⁸⁶ EPA. 2000.

existing water programs did not focus on control of non-point sources, including atmospheric deposition.⁸⁷

Another example of federal coordination is the Persistent Bioaccumulative Toxics Initiative (PBT), the goal of which is to further reduce risks to human health and environment from existing and future exposure to PBT through increased coordination among EPA national and regional programs.⁸⁸ According to one group, the primary goal of PBT is to reduce risk from priority pollutants, not virtual elimination of such pollutants. The strategy apparently relies on voluntary measures and plan development rather than implementing actual control mechanisms.⁸⁹

Regional coordination

Coordinated oversight over the water quality of the Great Lakes began in 1972 with the above-mentioned GLWQA. The International Joint Commission (IJC) was created at that time and was given oversight over the implementation of the GLWQA. The IJC has regulatory authority over certain water level and flow matters, and serves to advise governments about progress and emerging issues and problems.⁹⁰ Over the last three decades, the GLWQA has been amended to address the need for a more holistic and systematic approach towards pollution prevention and elimination. In 1978, the GLWQA was revised to adopt "an ecosystem approach to management."⁹¹ In 1987 it was revised to explicitly address the issue of atmospheric deposition, calling for further research and surveillance, and control mechanisms. In 1990, the International Atmospheric Deposition Network (IADN) under the GLWQA was established to assess the relative importance of atmospheric deposition to the Great Lakes and to provide information on pollutant sources. Loading estimates are made every two years from numerous monitoring stations.⁹²

The Great Lakes Regional Air Toxic Emissions Inventory was undertaken through an intergovernmental partnership involving the eight Great Lakes states, the province of Ontario, and U.S. EPA. The goal of this initiative is to present researchers and policy makers with detailed, basin-wide data on the source and emissions of 82 toxic contaminants.⁹³

In 1997, the US and Canada signed the Binational Toxics Strategy (BTS) to realize the GLWQA ultimate goals of zero discharge and virtual elimination. The BTS has identified a dozen "Level 1" priority pollutants for virtual elimination. BTS has committed to studying issue of long-range transport, and to working through the BTS and other international frameworks to address the issue. The US and Environment Canada have agreed to coordinate research, monitoring, and control programs.

⁸⁷ EPA. 2000.

⁸⁸ EPA. 2000.

⁸⁹ The Delta Institute. 2000.

⁹⁰ The Delta Institute. 2000.

⁹¹ The Delta Institute. 2000.

⁹² The Delta Institute. 2000.

⁹³ Great Lakes Commission (GLC). 1999. 1996 Inventory of Toxic Air Emissions: A Product of the Great Lakes Regional Air Toxic Emissions Project. As cited in The Delta Institute. 2000.

International initiatives

In 1979, 34 members of the United Nations Economic Commission for Europe signed the Convention on Long-Range Transboundary Air Pollution to address the issue of acid rain. This convention, which was the first internationally binding agreement to deal with regional air pollution, was the precursor to the Stockholm Convention on Persistent Organic Pollutants (POPs). Signatories to this POPs convention agree to take measures to eliminate or reduce the release of POPs into the environment.⁹⁴ While this accord is referred to as “a legally binding instrument,” and signing it commits the political leadership of each country to seek the authority to achieve the accord’s objectives, actual implementation will depend on the legal authority and economic capacity within each of the signatories, as well as the support of citizens.⁹⁵

Under the North American Free Trade Agreement, the trilateral Commission on Environmental Cooperation (CEC) was established in response to widespread concern over the environmental degradation that could result from trade liberalization. The CEC’s main focus is on persistent, bioaccumulative chemicals, including long-range transport and atmospheric deposition, and has specific goals for eliminating certain chemicals – PCBs for example. However, the CEC has no regulatory authority and depends on actions by national governments for implementation.

3. Appraising the progress of remedial action

Where monitoring data exists either locally or nationally, atmospheric deposition of pollutants of concern to the Great Waters has declined or remained relatively constant in recent years. Specifically, deposition of lead, cadmium, dioxins, furans, polycyclic aromatic hydrocarbons (PAHs), PCBs, some restricted or banned pesticides has declined in the Great Lakes, while deposition of nitrogen oxide (NO_x) has remained fairly constant. These trends may reflect the emission reduction programs of Clean Air Act, as well as outright bans of certain pollutants (for example, the phase out of lead from gasoline). The steady state of NO_x reflects the balance between Clean Air Act emissions controls and emissions increases due to economic growth⁹⁶

Actions taken by the EPA and other regulatory agencies have apparently had a positive impact on deposition trends. However, atmospheric deposition can still be a significant source of certain pollutants. For example, it is estimated that up to 40 percent of the total mercury deposited on U.S. waters and lands comes from the global reservoir of mercury. This deposition contributed to fish consumption advisories for roughly 70 percent of the Great Waters nationally as of 1997.⁹⁷

Moving forward, implementation of existing EPA regulation such as MACT is expected to further reduce emissions of mercury, NO_x, dioxins and furans, among other pollutants of concern. It

⁹⁴ Stockholm Convention on Persistent Organic Pollutants. <http://www.chem.unep.ch/sc/>

⁹⁵ Delta Institute, 2000, *Atmospheric Deposition of Toxics to the Great Lakes: Integrating Science and Policy*, Delta Institute, 53 W. Jackson Blvd., Suite 1604, Chicago, IL 60604, <http://www.delta-institute.org/>

⁹⁶ EPA 2000.

⁹⁷ EPA 2000.

may be difficult to regulate loadings of banned pesticides, as they come from remaining consumer stocks, evaporation from soils, resuspension of sediment, and long-term transport from other nations. Further reduction of such substances will likely require cleanup of contaminated soils and stockpiles as well as international support.⁹⁸

Pinpointing the management priorities

One significant shortcoming of current emissions control programs is that pollutant limits are set without consideration for how these pollutants interact with each other or for their impact as they accumulate in the environment.⁹⁹ For example, mercury emissions limits are established without considering how mercury might interact with PCBs. Addressing a pollutant not only its own impact on human and ecosystem health but also by its combined impact with other pollutants would apparently be a novel approach to standards setting.

The existence of numerous policy instruments and regulatory frameworks on the local, national and regional level demonstrates the policy makers' commitment to remedying toxic pollution in the Great Lakes. However, few of these instruments or frameworks have resulted in an integrated, multimedia strategy for either achieving committed goals such as virtual elimination or defined reductions.¹⁰⁰ For the most part, bi-national or international treaties have no power when it comes to reducing or eliminating pollutants. It is typically up to signatory nations or states to follow through on the objectives of the treaty – which may or may not happen depending on the political climate that exists. Several coordinated efforts exist on the U.S. federal level (e.g. Great Waters Program), but it may be too early to judge their effectiveness.

H. Climate Change Implications and Interactions

1. What is Known

The deposition of toxics are influenced by the amount of precipitation available to scavenge soluble substances to the surface and runoff is obviously also controlled by quantity, frequency and intensity of precipitation events. Precipitation patterns are expected to be influenced by global warming though considerable debate remains on temporal, spatial and volumetric magnitude of the changes. Climate scenarios suggest that the climate will be 2-4 °C (3.6-7.2 °F) warmer and about 25% wetter by the end of the 21st century in the Great Lakes region. There will also be fewer cold air outbreaks and less lake-effect snow in winter – especially around the southern lakes (Erie and Ontario)¹⁰¹.

⁹⁸ EPA 2000.

⁹⁹Delta Institute, 2000, *Atmospheric Deposition of Toxics to the Great Lakes: Integrating Science and Policy*, Delta Institute, 53 W. Jackson Blvd., Suite 1604, Chicago, IL 60604, <http://www.delta-institute.org/>

¹⁰⁰Delta Institute, 2000, *Atmospheric Deposition of Toxics to the Great Lakes: Integrating Science and Policy*, Delta Institute, 53 W. Jackson Blvd., Suite 1604, Chicago, IL 60604, <http://www.delta-institute.org/>

¹⁰¹ Effects of Climate Change on Heavy Lake-Effect Snowstorms near Lake Erie and other Great Lakes, <http://www.geo.msu.edu/glra/assessment/lake-effect.html>

2. What are the Significant Unknowns

Little confidence exists in the estimates of future precipitation pattern shifts save for the expectation fewer colder days should reduce lake-effect significance. Moreover, it is also unclear how or if the warmer climate would impact the degree and distribution of vertical mixing.

IV. FUTURES STRATEGY FOR THE UM

A. Research Opportunities

The Great Lakes are unique in that they are the largest fresh water resource in the United States; they cover three different climate zones, and represent a wealth of biodiversity¹⁰² and biological integrity. To protect these resources will require informed policy decisions on nonpoint source pollution and toxic deposition supported by informed input on matters of science, engineering, policy and other key areas. The design of these policies is challenged by the uncertainties in pathways and an integrated assessment of impacts and costs.

Based on the significant unknowns itemized in the preceding sections there appear to be opportunities for the University of Michigan to participate in or take a leadership role in air toxics deposition in several areas. These opportunities include: Research on atmospheric pathways of toxics from source to watershed; Research on integrated environmental assessment of toxics and other pollutants of concern; Research on climatic influences on future toxic deposition issues; and Research on integrated educational approaches to toxic air pollutants.

1. Pathways

Air/Surface Exchange

While there has been considerable research on the exchange of pollutants with vegetation and, to a lesser degree, forests there remains considerable uncertainty about the rate of dry deposition of toxics to watersheds, notably including urban watersheds. Research is needed to quantify urban deposition of pollutants through measurement programs, mass balance experiments and modeling.

Transport and Fate of Toxics

There are also unknowns about the cycling of toxics from the source, through the atmosphere to deposition and subsequent journey to the lakes. To improve current understanding of this process research is needed that will explore the processes involved. Rates of chemical conversion are speculative at the moment as are the mechanisms for interactions of toxics and biological surfaces.

¹⁰² Great Lakes Biodiversity Resources, <http://www.epa.gov/glnpo/ecopage/biodiver.html>

2. Climate and Toxics

Changes in Deposition Patterns

It is possible that in a few decades global warming will have affected many aspects of the Great Lakes climate. If this is true we must also be concerned about how switches from moist to drought or dry to deluged land will affect deposition and runoff.

Terrestrial and Aquatic Processing of Toxics

It is speculated that toxics may behave in a way similar to carbon as it passes through the biomass. If this is true it will be important to assess the processes of carbon cycling with an eye toward toxic material redistribution from soil to biota.

Exposure of Shoreline

It is possible that, in the future, we will encounter prolonged periods of drought resulting in significant lowering of the Great Lakes surface level. Under this scenario the expanded shoreline will expose sediment to the air. There has been little research to date on if these exposed lands pose a significant hazard to their locale. Drying materials could become airborne and may resuspend particles that had previously been deposited from the air.

3. Academic Opportunities

Provide opportunities for students to prepare to address air toxics issues.

At the undergraduate and graduate levels there are existing courses that need to be presented as a concentration, either through the Program in the Environment or the College of Engineering that prepare students for technical, policy and health-related professions needed to address the air toxics issues.

Provide a concerted outreach program to support formal and informal education on air toxics

A key to achieving significant reductions in air toxic emissions is to educate the public about the environmental cost and potential benefits of such efforts. Programs exist at the University of Michigan in areas of asthma education, weather education and air quality education that could be integrated through the sciences to provide support to schools and museums.