Strategy for Virtual Elimination of Persistent Toxic Substances. Volume 2. Appendices: Seven Reports to the Virtual Elimination Task Force

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A STRATEGY FOR VIRTUAL ELIMINATION OF PERSISTENT TOXIC SUBSTANCES

Volume 2

International Joint Commission
Commission mixte internationale
The photo illustrates a small portion of the rock paintings at the Agawa site on the north shore of Lake Superior. These paintings were reproduced on bark in the first half of the nineteenth century by an Ojibwa named Chingwauk. According to Chingwauk's explanation of the drawings, the mythical horned creature is Misshipeshu, the Great Panther or Lynx, who was the Great King of the Fishes; the serpents are representations of Mishikenahbik the Snake manitou; and to the left is a canoe containing five men. The drawings are part of a story involving a shaman called Myeengun (Wolf) who undertook a hazardous voyage, very likely in response to a vision.

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A STRATEGY FOR VIRTUAL ELIMINATION OF PERSISTENT TOXIC SUBSTANCES

Volume 2

APPENDICES

SEVEN REPORTS TO THE VIRTUAL ELIMINATION TASK FORCE

Windsor, Ontario

August 1993

ISBN 1-895085-66-7

NOTE

Volume 2 contains a series of seven reports to the Virtual Elimination Task Force. Except where noted, Appendices A through E are not consensus documents of the Task Force. The views expressed are those of the authors and, except as noted, do not necessarily represent those of the Task Force.
## APPENDICES

### A. APPLICATION OF THE VIRTUAL ELIMINATION STRATEGY TO PCB AND MERCURY

- Jeffery A. Foran

### B. CHLORINE: DEVELOPMENT OF A LONG-TERM STRATEGY FOR A BASIC FEEDSTOCK SUBSTANCE

- *A Report on Chlorine to the Virtual Elimination Task Force.* G.N. Werezak

### C. ECONOMIC INSTRUMENTS AND VIRTUAL ELIMINATION

### D. THE INJURY

### E. PROGRESS TO DATE
APPLICATION OF THE VIRTUAL ELIMINATION STRATEGY TO PCB AND MERCURY

Development of a Remediation Strategy
for a "Banned" Substance and for a Substance
with Natural and Anthropogenic Sources

A Report to
The Virtual Elimination Task Force

by Jeffery A. Foran

June 17, 1993

ACKNOWLEDGEMENTS

I extend thanks to Ylang Nguyen for assistance in research and preparation of this report. Thanks are extended also to David Dolan and members of the Virtual Elimination Task Force for providing information for this report. Finally, I am grateful to Dr. Marty Bratzel for advice and assistance throughout the conduct of this project.

DISCLAIMER

The views and opinions expressed in this appendix are those of the author and do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission. Quantitative source and loading data that are presented in this appendix may not reflect the most recent data available on PCB and mercury sources and loadings to the Great Lakes. Such data are continuously being contributed and refined. However, the source and loading data presented in this appendix are sufficient to demonstrate the major sources and pathways of PCB and mercury to the Great Lakes and thereby allow identification of actions necessary (but perhaps not sufficient) to virtually eliminate these substances from the Great Lakes.
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APPLICATION OF THE VIRTUAL ELIMINATION STRATEGY TO PCB AND MERCURY

INTRODUCTION

The purpose of the PCB and mercury case studies is to explore how the strategy presented in Chapter 3 of this report can achieve the virtual elimination goal. In particular, this appendix describes specific measures that can be taken, as well as the ecosystem improvements that should be possible beyond what has been achieved over the past two decades.

The general approach of this appendix is to focus on where and in what quantities PCB and mercury reside. This is achieved by identifying and quantifying sources and pathways by which they enter the ecosystem, as well as considering their uses and post-use fate and ultimately identifying intervention points.

We must recognize that it is easy to recommend a particular action. It is difficult, however, to ensure that action is taken using the legal, technological, economic, and societal tools and opportunities with all their inherent limitations. Even more difficult is achieving our environmental goals via recommended actions. Thus, the PCB and mercury examples provide an opportunity to focus efforts on the virtual elimination strategy presented in this report.

The discussion in this appendix is not intended to be exhaustive but, rather, representative of how we can approach the issue of virtual elimination. From the PCB and mercury examples, we can glean general principles that should be applicable to other persistent toxic substances and, hence, allow us to complete the journey toward the virtual elimination goal.

PCB is a synthetic organic substance that was manufactured in large quantities and widely used because of a number of desirable properties. Mercury is a naturally occurring metal whose bioavailability is enhanced by human use. These two persistent toxic substances were chosen for the case study examples because we have long recognized that they are responsible for many forms of injury to aquatic biota, birds, terrestrial wildlife and humans. Chronic, sublethal effects, as well as acutely toxic properties, are well documented in the peer-reviewed literature and have been discussed earlier in Appendix D. This injury reached its nadir in the late 1960s and early 1970s.

Ecosystem quality in the Great Lakes today is much improved from conditions two decades ago. Since PCBs, mercury, and other persistent toxic substances bioaccumulate in the tissues of living organisms, such improvements were particularly noted in fish and birds which are at or near the top of the food web. For example, Figure A-1 depicts the decrease in PCB levels in eggs from a herring gull colony in Lake Ontario (1).

This improvement is the result of legislative initiatives, technological actions, and other measures taken primarily in the 1970s. Some of these focused directly on PCB, mercury, and other persistent toxic substances, and others only incidentally. For example, both the United States and Canada banned the manufacture/importation of PCB and severely curtailed its use. For mercury, use of chlor-alkali technology was largely supplanted and use in numerous products reduced or eliminated.

At about the same time, major initiatives were undertaken to construct municipal and industrial waste treatment systems, and to clean up contaminants already in the ecosystem. The principal focus of these construction and cleanup programs was on "traditional" pollutants such as phosphorus, biochemical oxygen demand (BOD), and suspended solids. The treatment applied to point-source effluents and emissions coincidentally controlled, but did not eliminate releases of PCB, mercury, and other persistent toxic substances to the ecosystem, particularly those attached to particulate matter.

However, the declines in ecosystem concentrations observed in the 1970s have ceased. For example, Figures A-2 and A-3 depict PCB and mercury levels in rainbow smelt and lake trout for Lake Ontario.
Appendix A

Ontario. Although trends for subsequent data for the 1980s are more difficult to interpret, levels of some persistent toxic substances appear to have stabilized or to be increasing.

Present levels and possible future increases are cause for concern because, despite previous improvements, injury to living organisms is still occurring. For instance, the bald eagle has returned to the shores of the Great Lakes, but reproductive success is limited. Hatchery-reared lake trout thrive when introduced to the Great Lakes, but do not reproduce. Thus, many, including the Task Force and the Commission, have concluded that the Great Lakes Basin Ecosystem is not able to receive and assimilate persistent toxic substances (3,4).

Three questions arise regarding PCB and mercury concentrations in the Great Lakes ecosystem:

- Why have contaminant concentrations leveled off and, in some cases increased?
- How can we further reduce ecosystem contaminant levels?
- What are the consequences in terms of eliminating the injury associated with PCB, mercury, and other persistent toxic substances?

Several factors may be responsible for maintaining or increasing contaminant concentrations, including:

- Continued contaminant inputs, in part because the entire life cycle of the persistent toxic substance has not been addressed.
- The resistance of these contaminants to degradation.
- Recycling in the food chain and/or a change in the forage base for certain top-predator fish.
- An equilibrium shift: i.e. - desorption of contaminants from sediment as a result of reduced contaminant levels in the water column.
- Delayed transport of old material from land surface or temporary deposition areas in tributaries.

At present, it is not possible to establish all the causative factors for present contaminant levels and trends, or their relative significance. Nonetheless, one can still conclude that PCB and mercury are still entering the ecosystem and continue to be available. Therefore, a virtual elimination strategy must be designed and implemented, based on information presently available. As additional information becomes available, the actions taken within that strategy can be adjusted accordingly.

The remainder of this appendix explores application of the virtual elimination strategy to PCB and mercury. The appendix recognizes that the technology-based and water-quality-driven regulatory approach used in the past, which was necessary and directly responsible for the significant improvements to date, may not be able to deliver the further reductions required to achieve virtual elimination and the absence of injury. In addition, there are a number of legal, technological, economic, political, and philosophical barriers to further progress. Thus, application of the virtual elimination strategy reflects fundamental alterations in philosophy, thinking, and the way we do business. The strategy builds on the past and is expanded to encompass additional perspectives and to surmount present limitations.

Application of the strategy is comprehensive, with consideration for the complete life cycle of PCB and mercury. It is also effects driven, with a focus on prevention of injury in addition to management of inputs. And it encompasses less structured, non-regulatory economic and societal factors.

SOURCES AND PATHWAYS OF PCBs AND MERCURY

Human manufacture, use, and disposal are the ultimate sources of PCBs to the ecosystem while mercury releases occur from these as well as natural sources. The routes of transport to the Great Lakes ecosystem include atmospheric deposition, release from contaminated sediments, and direct point and nonpoint (non-atmospheric) discharges. Individual sources of PCBs and mercury include: hazardous waste sites, direct industrial discharges, overland runoff, release from landfills, spills and accidental releases, combustion of fossil fuels, re-evaporation from land and contaminated water bodies, releases from mining and extraction activities, releases from household and commercial uses, releases from municipal treatment and incineration facilities, and pesticides.

PCB

Global, United States, and Canada

There is an estimated 370,000 tons of PCB in the global environment which make up 30% of the world PCB production (5). Although the manufacture of PCBs was ceased in the late 1970s, 65% (783,000 tons) of the world's 1,200,000 tons of PCB production is still in use in electrical equipment and other products, or deposited in landfills and dumps, while only 4% of world production has been incinerated or has degraded. As of 1982, only 3% of the 640,000 tons of PCBs manufactured in the U.S. had been
destroyed while 140,000 tons was buried in landfills and 70,000 tons was estimated to be circulating through the environment (6). As of 1988, over 280,000 tons of PCBs were in use in the U.S. (7) and over 16,000 tons of PCBs were in use and over 12,000 tons are in storage in Canada (8).

There are numerous potential anthropogenic sources of PCB to the environment. PCBs have been used extensively in closed system electrical and heat transfer fluids (60% of total uses), in plasticizers, hydraulic fluids, flame retardants, inks and carbonless copy papers, and in household and commercial products such as capacitors in fluorescent light fixtures, consumer electronics, refrigerators, and air conditioners (9). Nearly all large capacitors made before 1977 contain PCBs and may be a major source of PCBs to the environment.

Travis and Hester (10) suggest that volatilization from spills, landfills, and road oils are important contributors of PCBs to the environment and that the annual PCB emission from sanitary landfills in the U.S. ranges from 10 - 100 kg/year. Voldner and Smith (6) estimated that municipal waste incineration contributed 5 tons/year of PCBs to the atmosphere in 1987. Other sources of PCBs to the environment include volatilization from lake surfaces, industrial discharges to air, and electrical power generation.

Great Lakes

Estimates of the source and pathway contributions of PCBs to the Great Lakes are shown in Table A-1. Most estimates indicate that the atmosphere is the predominant pathway for PCBs to Lake Superior (Figure A-4). Less information on comparative
PCB Loadings to Lake Superior

Total Loading = 358.7 kg/year

Source: Reference (17).

Contributions from pathways is available for the other lakes. However, the atmosphere and tributaries appear to be the predominant pathways for PCBs to Lakes Michigan, Huron, Erie, and Ontario, with tributaries likely contributing greater loads of PCBs to Lakes Erie and Michigan than the atmosphere (Table A-1).

In some cases, specific tributaries have been identified as important sources of PCBs to the Great Lakes. The Fox River (Wisconsin) contributes a majority of the tributary PCB load to Green Bay (11,12) although it is unclear what portion of this load actually reaches Lake Michigan. The Detroit River contributes a majority of the tributary PCB load to Lake Erie (13). However, Marti and Armstrong (11) caution that, although tributaries are a significant source of PCBs to Lake Michigan, because of large fluctuations in tributary concentrations and insufficient tributary sampling, the exact estimates of PCB loads contributed to Lake Michigan from tributaries and their sediments cannot be calculated.

Sources of PCBs to tributaries (as well as directly to the Great Lakes) include contaminated sediments, municipal and hazardous waste landfills, point discharges from municipal and industrial sources (municipal sewage treatment plants, metal casting operations, deinking operations, and paper mills handling recycled fiber), contaminated storm water and surface runoff, and spills. Contributions of PCBs from contaminated sediments, which reflect historical point and nonpoint source discharges, may be the primary source of PCBs to tributaries although leaks and spills of PCBs from existing uses may contribute as much as 50 tons/year in the Great Lakes region (6).

Dolan et al. (17) estimate that the total PCB load discharged directly to Lake Superior from municipal and industrial sources is approximately 17 kg/year. The estimated load of PCB from direct runoff to Lake Superior is 18 kg/year and 6 kg/year are estimated to derive from unmonitored areas.

The relative contributions of PCB to each of the Great Lakes from various pathways and the sources associated with each pathway are shown in Table A-2. Discussion of interventions associated with these pathways and sources occurs later in this appendix.

Mercury

Global, United States, and Canada

The world mine production of mercury in 1989 was between 5,800 and 7,000 tonnes and estimates of annual global emissions of mercury from anthropogenic sources (to all media) range from 11,000 to 20,000 tons (19,20). Approximately 4,500 tons of mercury are emitted to the atmosphere annually (19). The total anthropogenic emission of mercury (to all media) in the U.S. is estimated to be between 240 and 650 tons/year. Dolan et al. (17) have reported a natural global mercury emission rate of 3,500 tons/year and the estimated emission rate from natural sources of mercury in the U.S. (1976) was 1,018 tons (6).

There are numerous anthropogenic sources of
Table A-2
Pathways, Ranked in Order of Importance, and Sources
(Associated with Each Pathway) of PCBs to the Great Lakes

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Source</th>
<th>Superior</th>
<th>Michigan</th>
<th>Huron</th>
<th>Erie</th>
<th>Ontario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>M - Volatilization</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>mi - Municipal HWc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incinerators</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Municipal HW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Landfills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Industrial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Discharges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tributaries</td>
<td>M - Contaminated</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1†</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Sediments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I - Municipal HW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Landfills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Industrial/ Municipal Dischargers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Point Source</td>
<td>I - Industrial/ Municipal Dischargers</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Direct Nonpoint Sourceb</td>
<td>M - Contaminated Sediments</td>
<td>3</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>mi - Municipal HW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Landfills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>I - Spills</td>
<td>5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Source Contribution: M - Major, I - Intermediate, mi - Minor
† Primarily the Detroit River.
*b Nonpoint sources other than atmospheric deposition.
c HW = Hazardous waste.
NA No information available.

The total anthropogenic release rate for mercury was 17 tons/year compared with a release rate from natural sources of approximately 11 tons/year.

Sources of mercury to tributaries have been only poorly quantified. Contaminated sediments may be a less important source of mercury than PCBs to tributaries and ultimately to the Great Lakes. However, industrial and municipal wastewater discharges, use of mercury-based pesticides, and municipal landfills (deriving specifically from disposal of used batteries and other mercury-containing products) (21) are important sources of mercury to tributaries.

Point and nonpoint direct discharges are also important sources of mercury to Lake Superior. The total load of mercury from industries and from municipal wastewater treatment plants discharging directly to Lake Superior is approximately 73 kg/year, while the total load from direct runoff is 40 kg/year. Another 5 kg/year are contributed from combined sewer overflows and spills (17).

Natural sources of mercury may contribute from one quarter to one half of the total load of mercury to
Appendix A

Table A-3
Source and Pathway Loads (in kg/year) of Mercury to the Great Lakes

<table>
<thead>
<tr>
<th>Lake</th>
<th>Atmosphere</th>
<th>Tributary Industrial</th>
<th>Municipal/</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
<td>657</td>
<td>86</td>
<td>73</td>
<td>17*</td>
</tr>
<tr>
<td></td>
<td>2,181</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Michigan</td>
<td>1,568</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Huron</td>
<td>1,584</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Erie</td>
<td>782</td>
<td>2,584</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>723</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Ontario</td>
<td>568</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
</tbody>
</table>

* Other sources: Direct runoff - 40 kg/year; unmonitored areas - 38 kg/year; combined sewer overflows and spills - 5 kg/year

the Great Lakes. Primary pathways for contributions from natural sources are the atmosphere, direct inputs, and inputs via tributaries. Most natural sources of mercury to the Great Lakes may not be amenable to intervention.

Emissions of mercury may grow substantially by the mid-1990s as the municipal waste and sewage sludge incineration sectors grow (6), although these increases may be tempered by reductions in the quantity of mercury-containing material entering waste streams and by more stringent regulations on emissions from waste incinerators. Presently, 31 million tons of trash are burned at 176 incinerators in the U.S. By the year 2000, 53 million tons of municipal waste will be burned if all incinerators under construction and those planned come on line (19). An increase in coal combustion may also increase mercury emissions although more stringent controls on emissions may temper these increases. Emissions from coal burning power plants in the Midwest are likely an important source of mercury to the Great Lakes. The highest consumption of coal in the U.S. comes from the Ohio River Valley, with Indiana and Ohio among the states emitting the largest quantities of mercury from coal-burning power plants in the United States (19).

The relative contributions of mercury to Lake Superior from various pathways and the sources associated with each pathway are shown in Table A-4. Data for pathway and source contributions of mercury to the other Great Lakes are not available. Further discussion of interventions associated these pathways and sources occurs later in this appendix.

LOCATION, RESIDENCE, AND INTERVENTION POINTS OF PCB AND MERCURY IN THE GREAT LAKES ECOSYSTEM

Location and Residence

PCBs and mercury will occur in the dissolved phase in surface waters although, because of their relative hydrophobicity, substantial concentrations will also be found in sediments and in biota. As these substances, or some form of these substances, absorb readily to sediment particles, significant sediment concentrations of PCB and inorganic mercury can be found in regions where they have been discharged historically in large quantities or where they occur naturally (mercury). Inplace pollutants may be released to the water column either via natural processes (e.g. mercury methylation) or upon disturbance (see Reference (25)).

Significant quantities of PCB and mercury (in the organic form) will also occur in tissues of aquatic biota, the result of accumulation through both bioconcentration and biomagnification. In many cases, organisms higher in the food chain may contain greater concentrations of these substances than organisms lower in the food chain.

Estimates of the relative quantities of PCB and mercury in water, sediment, and biota have not been developed for the Great Lakes basin. However, Tanabe (5) suggests that approximately 60% of the 370,000 tons of PCBs in the environment occurs in
Figure A-5
Mercury Loadings to Lake Superior

Total loading = 1,117.8 kg/year

Source: Reference (17).

Figure A-6
Mercury Air Emissions in Michigan

27.9 tonnes/year

Source: Reference (17).
Table A-4
Pathways, Ranked in Order of Importance, and Sources (Associated with each Pathway) of Mercury to Lake Superior

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Source</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>M - Natural Sources</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>M - Fossil Fuel Combustion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M - Municipal HW(^b) Incinerators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M - Latex Paint(^c)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M - Nonferrous Smelting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Volatilization from WWTP(^d)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Municipal HW Landfills</td>
<td></td>
</tr>
<tr>
<td>Tributaries</td>
<td>I - Natural Sources</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>I - Industrial/Municipal Dischargers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I - Nonferrous Smelting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I - Pesticides</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Contaminated Sediments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Municipal HW Landfills</td>
<td></td>
</tr>
<tr>
<td>Direct Point Source</td>
<td>I - Industrial/Municipal Discharges</td>
<td>3</td>
</tr>
<tr>
<td>Direct Nonpoint Source(^a)</td>
<td>I - Natural Sources</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>I - Municipal HW Landfills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mi - Contaminated Sediments</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>mi - Spills</td>
<td>5</td>
</tr>
</tbody>
</table>

Source Contribution: M - Major, I - Intermediate, mi - Minor
\(^a\) Nonpoint sources other than atmospheric deposition.
\(^b\) HW = Hazardous waste.
\(^c\) Mercury use as a fungicide in latex paints has been banned; therefore, contributions from this source may be reduced over time.
\(^d\) WWTP = Wastewater treatment plant.

oceanic waters while 35% occurs in sediment. No estimate of the quantity in biota was made. Sixty-five percent of the world’s PCB production is still either in use or occurs in electrical equipment that has been deposited in landfills. He suggests also that disposal of PCBs used in older transformers and capacitors will reach a peak in the 1990s. It may be reasonable to assume that similar relationships exist for PCBs in the Great Lakes basin.

The atmosphere is an important (although temporary) reservoir for PCBs. Travis and Hester (10) estimate that 900,000 kg (900 tonnes) of PCBs cycle through the U.S. atmosphere each year. They suggest also that soils and sediments of lakes and oceans are the ultimate reservoirs for more than 99% of the total mass of PCBs in the environment.

Unlike PCBs, the atmosphere may be a relatively less important reservoir for mercury, containing about 1,000 tons. The dominant process controlling the distribution of mercury compounds in the environment is sorption of nonvolatile forms to soil and sediment particulates (20), where most of the global mass of mercury may be found.
Intervention Points

The relative contributions of PCBs and mercury from various pathways and sources are presented in Tables A-2 and A-4, respectively. The atmosphere is the most important pathway for loadings of PCB to Lakes Superior, Huron, and Ontario. The atmosphere is also the most important pathway for loadings of mercury to Lake Superior (information on pathways to the other Great Lakes is not adequate for assessment). Tributaries are also an important pathway for PCB and mercury loadings to the Great Lakes, and are the most important pathway for Lakes Michigan and Erie, contributing at least 75% of the total PCB and mercury load to Lake Erie. Direct municipal and industrial discharges and direct nonpoint sources (non-atmospheric) contribute smaller proportions of the total loads of PCBs and mercury to Lake Superior and likely to the other Great Lakes.

Examination of the pathways and sources of PCB and mercury to the Great Lakes provides opportunities to identify intervention points, or points where steps may be taken toward the virtual elimination of these substances from the Great Lakes ecosystem. As atmospheric deposition and tributaries are the pathways which provide the largest loadings of PCB and mercury, some of the sources to tributaries and to the atmosphere can be identified as intervention points.

Means of Intervention

Intervention in natural releases of mercury to the environment is likely unrealistic; therefore, the focus of the following discussion is on anthropogenic sources, and in some cases pathways of PCB and mercury.

Treatment-based technological solutions are available to reduce many of the direct discharges of PCBs and mercury to the Great Lakes and their tributaries from municipal and industrial point sources. Similar treatment-based technological solutions are available to reduce point discharges to the atmosphere, for example from incineration processes or combustion of fossil fuels. However, many existing treatment technologies, for example Venturi scrubbers or electrostatic precipitators for mercury removal from stack discharges, are relatively ineffective. Newer and more effective treatment technologies - activated carbon adsorption, ultraviolet radiation-ozonation, and reverse osmosis - are available for PCBs in wastewater and other discharges (22). More effective technologies such as activated carbon injection, activated carbon/lime injection, sodium sulfide injection, and wet scrubbers are also available for mercury with removal efficiencies as high as 95% (19).

Although some treatment technologies are relatively effective in reducing the concentration of PCBs and mercury from sources at the point of discharge, they will not accomplish virtual elimination; rather, they will remove PCBs and mercury to levels limited either by the removal efficiency of the technology or by deductibility. Virtual elimination can only occur via approaches that ultimately eliminate the contaminants from pathways and sources prior to the point where treatment and control are applied, thus preventing their release and discharge in any amount.

Discharge elimination for sources of PCBs and mercury can occur through pollution prevention. The basis for pollution prevention (also termed source reduction) is a net reduction (and for the purposes of this report, elimination) of toxic pollutants discharged to surface waters and other media through reduction and elimination of the use of the chemical. Use reductions and elimination may be accomplished through chemical bans or phase-outs, product modifications or bans, and behavior changes which affect product consumption or use. They may also be effected through industrial process modifications which include more efficient chemical use, chemical substitutions, and recycling, although U.S. EPA does not recognize recycling alone as a component of pollution prevention.

One fundamental component of the pollution prevention approach to virtual elimination of PCB and mercury discharges is the cessation of use of PCB and mercury in production and manufacturing processes. Cessation of manufacturing has been accomplished for PCBs, although substantial stocks of PCBs continue in use in electrical and other equipment. The mining and use of mercury also continues in many products and processes. However, elimination of PCB and mercury from production and manufacturing processes will not result in elimination of discharges from all pathways because of existing contamination of water, sediments, and soils with these substances. Therefore, remediation and treatment must be combined with prevention approaches to achieve the virtual elimination of PCB and mercury discharges to the Great Lakes.

The following proposed actions include combinations of treatment, remediation, and prevention-based approaches to address sources and pathways of PCB and mercury to the Great Lakes. Accompanying many of the proposed actions is a brief discussion of regulatory and non-regulatory mechanisms to implement the actions as well as a brief discussion of barriers to implementing the action. Although these proposed actions are applicable to activities in both the U.S. and Canada, legislative or other regulatory mechanisms to implement proposed actions have a substantial U.S. bias. This stems from the author’s relatively limited knowledge of Canadian legislation and regulatory mechanisms available to implement individual actions.

The actions presented below correspond with those presented in Table A-5 (PCB) and Table A-6 (mercury).
<table>
<thead>
<tr>
<th>SOURCE</th>
<th>REMEDIATE</th>
<th>TREAT</th>
<th>PREVENT</th>
<th>BARRIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAJOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contaminated Sediments (1)</td>
<td>Removal and disposal in combined disposal facilities for regions serving as important sources (e.g. Fox River).</td>
<td>Treatment/destruction of PCBs required. Technology not presently available although under development. Research and development necessary.</td>
<td>Eliminate existing and new discharges (industrial/municipal direct, municipal hazardous waste landfills, etc.).</td>
<td>Costs. Extent of contamination. Availability of technology. Public opposition.</td>
</tr>
<tr>
<td>Volatilization (2)</td>
<td></td>
<td></td>
<td>Prevention via source control, e.g. contaminated sediments, atmospheric discharges, etc.</td>
<td>Identification and elimination of sources.</td>
</tr>
<tr>
<td><strong>INTERMEDIATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MINOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WWTP = Wastewater treatment plant.
IPP = Industrial pretreatment program.
### Table A-6
**Actions to Reduce Mercury Loads to the Great Lakes**
(Numbers in Parentheses Correspond with Proposed Actions in Text)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>REMEDIATE</th>
<th>TREAT</th>
<th>PREVENT</th>
<th>BARRIERS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAJOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incinerators(2)</td>
<td></td>
<td>Require best available treatment technology on all existing discharges.</td>
<td>Phase out and ban use of mercury in products such as batteries.</td>
<td>Legislation/enforcement. Costs. Logistics.</td>
</tr>
<tr>
<td>Latex Paint (3)</td>
<td></td>
<td></td>
<td>Ban use of mercury as a paint fungicide.</td>
<td>None. Legislation/enforcement.</td>
</tr>
<tr>
<td>Nonferrous Smelting(4)</td>
<td></td>
<td>Require best available treatment technology.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INTERMEDIATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesticides (5)</td>
<td></td>
<td>Require best available treatment technology on all existing discharges.</td>
<td>Ban from formulation and use</td>
<td>Resistance from users and manufacturers.</td>
</tr>
<tr>
<td><strong>MINOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contaminated Sediments (9)</td>
<td></td>
<td></td>
<td>Eliminate existing and new discharges (industrial/ municipal direct, municipal hazardous waste landfills, etc.).</td>
<td>Costs. Extent of contamination. Availability of technology.</td>
</tr>
</tbody>
</table>

**WWTP** = Wastewater treatment plant.
**IPP** = Industrial pretreatment program.
ACTIONS TO TAKE (WITH TIME FRAMES)

S - Immediate/short term
   (no longer than five years)
M - Intermediate term (5 - 20 years)
L - Long term (> 20 years)

T - Treatment (usually at the point of release)
R - Remediation
P - Prevention

PCBs

1. Virtually eliminate PCB releases from contaminated sediments.

   Where contaminated sediments are a major source of pollutants to the Great Lakes, removal (with ultimate destruction) or in situ destruction is the only option to eliminate this source. Therefore, this action should occur first in highly contaminated regions serving as important sources of PCBs to the Great Lakes (e.g. the Fox River and other tributaries).

   Presently, the only sediment removal option in use is dredging (23). Several dredging techniques are available although none remove 100% of contaminated sediments. Once contaminated sediments are dredged, they must be stored, treated, or destroyed. Most contaminated sediments in the Great Lakes basin are presently placed in confined disposal facilities (either upland or in-water). CDFs are designed to retain greater than 99.9% of disposed sediment particles. Water is drained from the CDF during disposal operations and must be treated if it contains residual contaminants prior to release into the environment (23). CDFs are not intended as a treatment technology for PCB- or mercury-contaminated sediments. Rather, they are intended to be used as storage sites until appropriate treatment technologies become available. Removal and storage of PCB contaminated sediment in CDFs until destruction technology is developed has been recommended for the Great Lakes basin (22).

   Technologies that may be useful for remediation of contaminated sediments include: biological treatment; extraction; alternate heat processes; chemical treatment; conventional incineration; fixation/stabilization. All of these technologies can be applied after pretreatment mechanisms which are designed to reduce the volume of sediment and concentrate the quantities of pollutants.

Biological treatment is viewed as a potentially important technology for in situ treatment of contaminated sediments. This technology is expected to be relatively inexpensive and will leave sediments in a more natural state after treatment. However, biological treatment is not yet available for commercial application (23) and further research on this technology is necessary.

Remedial technologies that have been applied full-scale include the Lurgi Travelling Grate Pelletization Process and the Indirectly Heated Thermal Desorption Process. Both are considered very effective (greater than 99.9% destruction) with low-to-moderate costs. Other available full-scale technologies include Rotary Kiln and Circulating Bed Combustor incinerators, both of which are highly effective (> 99.9% destruction) but also have high costs. The Acres/Derrick Pretreatment process, the Ecologic Waste Destructor (ineffective for heavy metals), and the Aostra Taciuk Process (ineffective for heavy metals) have been applied in bench-scale demonstrations and may be useful for full-scale application. The Ecologic Waste Destructor had a destruction efficiency for organic contaminants of greater than 99% although it is relatively expensive.

A definitive destruction technology for PCB-contaminated sediment has not been identified. Research should continue to identify the most cost-efficient methodology to destroy PCBs in sediments.

A combination of conventional and innovative mechanisms will likely be necessary to implement this action. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA - Superfund) provides a readily accessible (conventional) legislative tool in the U.S. to pursue the cleanup of contaminated sediments where sediments have been included as part of a site on the National Priorities List. For example, the Kalamazoo River has been recognized for many years as an important source of PCBs to Lake Michigan. The PCBs derive from heavily contaminated sediments upstream from the river's mouth, and continuing contamination of sediments also occurs from PCBs contained in landfills near the river. Both the river and associated landfills have been listed on the NPL under Superfund, responsible parties have been identified, and some funding for clean-up appears to exist. Therefore, sediments contaminated with PCBs can be removed and destroyed and PCBs in landfills can be addressed (either removed and destroyed or capped) under the Superfund law.

Non-regulatory approaches will also be necessary to achieve remediation of contaminated sediments, particularly where sediment cleanup is not covered under Superfund. For example, mechanisms such as point/nonpoint source trading - where point source dischargers of minimal quantities of PCBs can defer achieving zero discharge by cleaning up inplace
pollutants - may result in more rapid removal of PCBs than conventional mechanisms that rely on legal or statutory mechanisms (see (24) for a description of this approach).

There are several barriers to implementation of this option. One of the most critical barriers is the tremendous quantity of PCB-contaminated sediment in the Great Lakes basin and the associated high costs of removal and destruction of PCBs in sediments, particularly where parties responsible for the original contamination are no longer in business or are unable to pay for cleanup. Funding mechanisms such as local or state bonds or taxes on water use must be developed to cover the costs of sediment removal and PCB destruction.

Other barriers include: local opposition to storage of highly contaminated sediments in CDFs or in upland waste storage facilities; local opposition to incineration of hazardous waste where incineration may pose some (at least perceived) health threat to nearby communities; and the legal and political maneuvering that commonly accompanies efforts to clean up sites on the NPL.

To deal with each of these barriers, educational activities must be developed that improve knowledge of the risks and benefits of removal and destruction technologies. Concurrent with educational activities must be development of efforts to ensure that affected communities will be fully involved in clean-up and destruction, including identification of the technologies to be used for clean-up and identification of the location of activities and technologies that will be utilized for storage and destruction. These efforts must be focused on ensuring that the best technology available will be used to prevent exposure to nearby communities during contaminant removal, storage, and destruction. Finally, educational activities must include information on the potential mechanisms available to fund sediment cleanup and determination made of which funding mechanisms may be the most acceptable to affected communities.

2. **Reduce and virtually eliminate volatilization of PCBs from lake surfaces (and other sources) to the atmosphere.** (L)

Atmospheric emissions from lake surfaces are generally not amenable to the application of control (treatment) technologies. Reduction or elimination of PCB volatilization from lake surfaces will require elimination of PCBs from surface waters, which can only be accomplished through control of sources (sediments, landfills, point sources, etc.), via remediation, treatment, and prevention.

3. **Virtually eliminate PCB contributions from waste sites.**

R/P Ensure that PCBs in landfills are prevented from migrating off-site (via air, groundwater, runoff, etc.). (S)

P Prohibit disposal of PCB-containing materials such as ballasts in light fixtures, capacitors, and other PCB-containing equipment in landfills. (S)

T Destroy PCBs in existing equipment. (L)

R/T Remove and destroy PCBs in municipal/hazardous waste landfills. (L)

Landfills (both municipal and hazardous waste) contain large quantities of PCBs, some of which enter the Great Lakes via runoff or volatilization. These sites are important sources of "new" PCBs to the Great Lakes and, as such, should receive high priority for control. Several steps will be necessary to address PCB inputs from waste sites. First, existing sites that are contributing PCBs to the Great Lakes and their tributaries (e.g. sites near the Kalamazoo and Saginaw Rivers) must be managed to prevent off-site migration of PCBs (via all routes including runoff, volatilization, etc.). This action can be implemented in several ways including temporary capping or sealing of landfills, and ultimately removal and destruction of contained PCBs. Technology similar to that discussed in action #1 is available to implement this action.

A prevention-based approach is also necessary to address this source. Future deposition of PCBs (from or in equipment, oils, ballasts in light fixtures, capacitors, etc.) in landfills should be prohibited. This proposed action is presently implemented to some degree under the Toxic Substances Control Act (TSCA) although it is in no sense a prohibition on PCB disposal. Rather, equipment containing PCBs in concentrations greater than 500 ppm must presently be drained and solvent flushed prior to disposal in a chemical waste landfill (PCBs drained from equipment must be incinerated). However, draining and flushing does not remove all PCBs from equipment; in fact, substantial quantities may still exist in equipment after draining and flushing which will then be deposited in landfills (7). Equipment containing PCBs in concentrations from 50 - 499 ppm must only be drained (not flushed) and drained equipment can then be disposed of in unregulated (municipal) landfills. Finally, equipment containing less than 50 ppm PCBs can be deposited in unregulated (municipal) landfills without draining.

A complete prohibition on the disposal of PCBs or PCB-containing equipment in landfills would
require modification of TSCA or its interpretation in 40 CFR 761.60, or modification of other statutes such as the Resource Conservation and Recovery Act (RCRA). Alternatively, innovative mechanisms such as economic incentives that encourage the collection of PCB-containing equipment at approved collection points (presently used in Sweden (21)) with subsequent destruction, or a substantial surtax on products or processes that result in disposal of PCBs may be more successful in reducing and ultimately eliminating disposal of PCB-containing equipment in landfills than changes in existing legislation.

Destruction of PCBs from equipment and other sources can occur through use of fixed and mobile treatment technologies, assuming a proper "regulatory environment" is in place. Extensive experience in, and technology for PCB destruction exists in both Canada and the U.S. Destruction technology is associated primarily with incineration (22). The efficiency and costs of PCB incineration have not been presented in detail, although PCB removal efficiencies of greater than 95% have been associated with treatment (incineration) processes used in industrial facilities.

Prevention of off-site migration of PCBs from existing waste sites can be accomplished through a combination of conventional and innovative mechanisms that include voluntary implementation by responsible parties, use of existing legislation (Superfund), or through legal action. CERCLA provides a readily accessible (conventional) legislative tool to pursue the clean-up of contaminated waste sites. Innovative (non-regulatory) mechanisms such as presented in proposed action #1 may also be useful. Regardless of the mechanism, however, prevention of off-site migration via capping or similar techniques should be considered temporary and be accompanied in the longer term by removal and destruction of contained PCBs.

Barriers to implementation include identification of responsible parties to implement actions (particularly where sites are not addressed under Superfund), substantial costs associated with implementation of remedial actions, and local opposition to removal and destruction actions similar to those identified in action #1 (contaminated sediments). A ban on disposal of PCB-containing equipment, implemented through regulation, will likely receive substantial resistance from entities subject to such regulation. Resistance may stem from increased costs associated with destruction rather than disposal of PCBs in equipment. In this case, non-regulatory approaches to disposal prohibitions (e.g. surtax, economic incentives, etc.) may be more acceptable. Finally, resistance to implementation of destruction technologies may come from local communities where those technologies are perceived to impose health threats on local communities. Resolutions to at least some of these problems are similar to those presented in action #1 above.

Appendix A

4. Reduce and ultimately eliminate discharges of PCBs from municipal and industrial point sources. (S,M)

This proposed action will require implementation of a combination of treatment-based (T) and prevention-based (P) approaches.

P Develop and implement pollution prevention plans and activities for direct and indirect industrial dischargers of PCBs. (S)

This action can be implemented through regulatory or voluntary mechanisms. Implementation through regulatory mechanisms may necessitate development of new, or modification of existing legislation to require pollution prevention planning. Development of such legislation has occurred in some states and is under discussion at the national level. Resistance to pollution prevention plans required through legislation will come from industry which may not be receptive to a command-and-control approach to pollution prevention planning. Therefore, non-regulatory mechanisms to ensure pollution prevention (planning and implementation) may be appropriate. Such mechanisms may include public commitments from industry to implement pollution prevention activities such as has occurred under the U.S. EPA 33/50 program. Economic incentives may also be useful to drive industrial pollution prevention activities.

Barriers to the development and implementation of pollution prevention activities include problems associated with the existing command-and-control approach to pollution control. This approach, which is usually media specific, may "hinder efforts to implement effective prevention strategies because it encourages regulators to focus on a particular medium therefore discouraging a multimedia approach to [implementing] prevention" (26).

Another barrier may be the lack of expertise necessary to develop and implement the process changes necessary to prevent and eliminate pollution, particularly in small companies. Resource constraints may also inhibit efforts to change manufacturing processes to those that prevent pollution. Finally, state or provincial and local jurisdictional resistance to encourage or require the adoption of pollution prevention strategies may also be a substantial barrier to pollution prevention. Jurisdictional resistance may stem from the perception that some actions might lead industries to relocate in regions with less stringent requirements for pollution control and prevention (26).

P Require municipal dischargers that receive industrial process waste to develop and implement enforceable IPPs which include pollution prevention plans for each industrial discharger of PCB. (S)
This proposed action should be implemented under Clean Water Act programs that address industrial pretreatment programs (IPP). Presently, inclusion of pollution prevention programs in IPPs is not required and may necessitate some modification in the statute or supporting rules. Barriers to this action are similar to those discussed elsewhere in this section.

5. Prevent PCB spills through implementation of best handling/management programs (good housekeeping practices). (S)

Removal of PCB from current use and destruction of PCBs in equipment and in storage will eliminate the potential for spills. Concurrent with removal and destruction activities, best management practices should be employed to prevent spills during storage, use, and transport. (S)

6. Reduce emissions from hazardous waste incinerators as much as possible during PCB destruction activities. (S)

Incineration will likely be an important mechanism for the destruction of existing stocks of PCBs. Where incineration or other technologies are employed to destroy PCBs, best available treatment/removal technologies should be utilized to ensure the lowest emissions possible from incinerators and other sources utilized during destruction. Some activity to implement this action is occurring under the U.S. Clean Air Act.

**Mercury**

1. Reduce (and eliminate where possible) mercury emissions from fossil fuel combustion.

T Require best available removal technology for stack emissions from coal-burning power plants. (S)

P Develop and implement programs to enhance energy efficiency and reduce reliance on coal (includes shift to reliance on natural gas). (S/M/L)

P Require use of clean coal in all coal burning plants in the Great Lakes basin (perhaps in midwestern U.S.). (M)

These proposed actions may be especially important in the Midwest and Great Lakes basin where a majority of the country’s coal combustion occurs. Coal cleaning can reduce mercury concentrations and emissions. Currently 40 - 50% of coal burned in the U.S. is cleaned with an average mercury removal of 30% (but as high as 68%). However, this process may only shift mercury to another medium. A more effective mechanism to work toward virtual elimination for this source is the replacement of coal and fuel
oil with natural gas which contains significantly less mercury. Pursuit of virtual elimination for this source can also occur through activities that result in reductions in energy consumption. An example is provided by U.S. EPA's Green Lights program.

McCorquodale et al. (21) suggest that "the most significant reductions in mercury emissions can be achieved by reducing energy consumption due to conservation or by the use of low mercury fuels, such as natural gas." Caution should be used however with options to reduce energy consumption through use of fluorescent bulbs. Although this option will reduce energy use (requiring less fossil fuel consumption), fluorescent bulbs contain mercury; therefore, fluorescent bulb recycling and recovery of mercury are necessary. Recovery activities have been effective in Europe although research is necessary to better capture mercury in usable form. Minnesota now prohibits businesses from disposing fluorescent lights in waste streams and businesses are required to store used fluorescent bulbs until recovery systems become available in the state, or to ship used bulbs to existing recovery facilities. These approaches may be useful throughout the Great Lakes basin as part of energy use reduction activities.

Implementation of this action will require a combination of regulatory and non-regulatory approaches. Best removal technology for stack emissions and the use of cleaned or cleaner coal could be required under the Clean Air Act (CAA). The CAA Amendments of 1990 required some improvements in technologies used to control stack emissions of mercury although installation of these technologies (which may not occur until the year 2000) will not eliminate the discharge of mercury from stack emissions. Further reductions in mercury emissions to the atmosphere may require further amendment of the CAA as well as reductions in energy demand and switches to cleaner fuels such as natural gas. Implementation of some programs that increase energy efficiency (or a switch to natural gas) have been implemented to date on a voluntary basis. Others may include full-cost accounting where the cost of environmental and human health damage associated with mercury discharges from fossil fuel combustion is passed on to consumers. Substantial increases in the costs of "dirty" fuels would likely result in shifts to less costly "cleaner" fuels as well as reduction in the use of fuels.

Barriers to the elimination of mercury emissions from fossil fuel combustion include the development and implementation, through the 1990 CAA Amendments, of regulations that require improvements in treatment technologies but do not achieve virtual elimination nor require pollution prevention. Where virtual elimination is not set at least as a goal with accompanying requirements for prevention-based approaches, further reductions beyond those achieved with improved technology may be impossible.

### Appendix A

2. Eliminate mercury discharges from incinerators. (S/M)

This proposed action can be implemented through the following pollution prevention mechanisms:

- **P** Develop and implement programs to recover spent mercury in batteries, thermostats, paint cans, chlor-alkali cells, fluorescent lights, etc. (S)

- **P** Require reductions in the amount of mercury used in alkaline batteries and other commercial products (S) and ultimately phase out these uses. (M)

- **P** Prohibit use of devices containing mercury in new buildings or in building renovation. (S) Recover switches and thermostats containing mercury during building renovation.(S)

Reductions of mercury discharges from incinerators can be achieved through implementation of treatment/removal technologies. However, treatment-based approaches may be quite costly and will not eliminate discharges of mercury from incinerators. Rather, a large array of pollution prevention/source control activities, which can be implemented in the short term for this source, will more efficiently reduce (and ultimately eliminate) mercury discharges from this source.

Pollution prevention/source control approaches should be focused on products, such as batteries and thermostats, in which mercury is used, which are discarded after commercial use, and ultimately end up in municipal waste streams, some of which is incinerated. For example, alkaline batteries accounted for 70% of the total mercury discarded in all batteries in 1989 (19). Some manufacturers are now reducing or eliminating mercury from alkaline batteries. Removal of mercury from mercuric oxide batteries (per substitution with zinc air batteries) is also necessary. Efforts to achieve mercury reductions in batteries can be modelled after Minnesota's mercury-in-battery law which is designed to restrict mercury to 0.025% for alkaline batteries by January 1992; to ban all mercury from alkaline batteries by 1996; to ban the sale of mercuric oxide button cells; and to require manufacturers to arrange for the collection and processing of used batteries or have manufacturers reclaim batteries themselves.

Non-regulatory mechanisms are also appropriate to reduce and ultimately eliminate the use of mercury in commercial products such as batteries. For example, full-cost accounting could result in substantial increases in the price of products that contain...
Appendix A

made, states should take immediate action to ban the use. Federal and state legislation provides a precedent for such a ban. However, resistance may come from manufacturers of the pesticides because of loss of sales. Relatively few other barriers to this action should exist.

6. Reduce and eliminate industrial and municipal point source discharges to surface waters.

P Develop and implement pollution prevention plans for industrial dischargers. (S)

This action can be implemented through regulatory and voluntary mechanisms. (See proposed action #4 for PCB)

P Assure that municipal dischargers have effective and enforceable IPPs in place which include pollution prevention plans for each industrial discharger. (S)

This action should be implemented under Clean Water Act programs that address industrial pretreatment programs. (See proposed action #4 for PCB)

P Replace (phase out) mercury cells in chlor-alkali plants by non-mercury methods. (S)

Mercury emissions in Canada were reduced from 24 tons/year to one ton/year from 1970 to 1982 (from chlor-alkali industry) as a result of the replacement of mercury cell chlor-alkali plants by non-mercury methods (implemented through more stringent air pollution control regulation in Canada). Action to reduce reliance on mercury cells in chlor-alkali plants is continuing.

T Require all direct industrial and municipal dischargers of mercury to meet water quality criteria and standards defined by the Great Lakes Initiative. (S)

T Require all direct industrial and municipal dischargers to install best available treatment technology. (S)

See proposed action #4 for PCB for discussion of these actions.

7. Eliminate mercury inputs from municipal/hazardous waste landfills.

P Phase out/prohibit disposal of mercury-containing materials in landfills (e.g. ballasts in light fixtures, batteries containing mercury, etc.). (S/M)
**Appendix A**

| P | Develop and implement programs to recover spent mercury in batteries, thermostats, paint cans, chlor-alkali cells, etc. (S) |
| P | Require reductions in the amount of mercury used in alkaline batteries (S) and phase out mercury-based batteries. (M) |
| P | Prohibit use of devices containing mercury in new buildings or in building renovation. (S) Recover switches and thermostats containing mercury during building renovation. (S) |

Implementation of these actions, and barriers to implementation are discussed in proposed action #3 (PCB) and proposed action #2 (mercury).

8. Prevent mercury spills through implementation of best handling/management programs (S) and ultimately through elimination of mercury use in products and processes. (M)

9. Determine the extent of sediment contamination by mercury, remove and recover as necessary, and eliminate existing and new sources through prevention as described above.

Where contaminated sediments contribute significant quantities of mercury to the Great Lakes, their removal and recovery of mercury from sediments may be necessary. Further, elimination of existing and new discharges of mercury from point and nonpoint sources is necessary, as described in proposed action #6, to prevent further sediment contamination.

**EXPECTED ENVIRONMENTAL RESPONSE**

The mass balance model described in Chapter 5 can be used to estimate the expected environmental change, in response to reduced inputs of PCB and mercury to the ecosystem. The change is projected as decreases in water, sediment, and biota concentrations over time. Figure 6 presents the expected change in PCB concentrations in water and sediment in Lake Superior in response to assumed input reductions. The projections are obtained by running the mass balance model with reduced loadings which are based on the actions discussed above. The degree to which the system recovers, and the time it takes to do so, are dependent on the severity or vigor of the load reduction efforts.

**IMPLEMENTING INTERVENTIONS**

Authority to control or prevent PCB and mercury discharge and disposal in the U.S. exists under several statutes including the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act, and the Toxic Substances Control Act; and in Canada under the Canadian Environmental Protection Act, the Canadian Fisheries Act, the Ontario Environmental Protection Act, and the Ontario Water Resources Act (27). However, a comprehensive ban on the use, storage, discharge, and disposal of PCB and mercury has not occurred under any of these statutes.

The strongest legislative authority to “virtually eliminate” chemicals through ban or phase-out exists under the U.S. Toxic Substances Control Act (TSCA - industrial chemicals), the U.S. Federal Insecticide Fungicide and Rodenticide Act (FIFRA - pesticides), and under the Canadian Environmental Protection Act (CEPA). Section 6 of TSCA and FIFRA and Section 18(1) of CEPA enable the Administrator or Minister of implementing agencies to prohibit or limit the import, manufacture, processing, sale, use, or release of a substance, where that substance poses an unreasonable risk or significant danger to humans or the environment (28). Section 40 of CEPA also gives the Minister authority to require replacement of products of concern with others not posing a danger to the environment or take any other measures for protection of the environment or of human health (27). Thus, TSCA and CEPA may provide the most effective regulatory tools to achieve the virtual elimination of PCBs and mercury in the Great Lakes basin. In fact, the manufacture of PCBs has been banned under TSCA, and PCB manufacture and discharge were banned under the Canadian Environmental Contaminants Act (now CEPA) although use of PCB is still allowed in equipment under both statutes.

There is relatively little argument that PCBs and mercury are hazardous environmental contaminants. Yet, a comprehensive ban on these substances (use, storage, discharge) has not been implemented in either the U.S. or Canada. Failure to implement existing statutes to ban or phase-out (to achieve the virtual elimination of) PCBs and mercury has been attributed to:

- Lack of political will.
- Inadequate identification of injury and causal agents.
- Preparation and transmission of a valid scientific case.
- Fear of challenges through litigation.
- Reluctance to use an interagency multimedia approach.
- The absence of waste destruction technology and requisite economic resources.
- Questions about what constitutes a *de minimis* quantity or concentration (28).

Of course, even if comprehensive bans on PCBs and mercury were implemented (including uses) either under TSCA or CEPA, such bans would not address the tremendous quantities of PCB and mercury that already exist in soils, sediments, and other environmental compartments, or in existing equipment (transformers, lights, batteries, etc.) as well as in municipal and industrial discharges.

Addressing existing reservoirs of PCBs and mercury through legislation will likely require aggressive implementation and perhaps amendment of statutes other than TSCA or CEPA. These include: The U.S. Clean Water Act (CWA); the U.S. Clean Air Act (CAA); the U.S. Resource Conservation and Recovery Act (RCRA); the U.S. Hazardous Materials Transportation Act (HMTA); the U.S. Comprehensive Response, Compensation, and Liability Act (CERCLA - Superfund); the Ontario Environmental Protection Act; and the Ontario Water Resources Act. Regardless of the statutory basis for the control of PCB and mercury discharges to the Great Lakes, however, further effort to amend these other statutes will be required so that they can be implemented effectively to treat, remediate, and most importantly prevent pollution from PCB and mercury.

Implementation of the proposed actions presented in this appendix through the multitude of applicable federal, state, or provincial statutes will likely result in piecemeal or fragmented efforts to control environmental pollution by PCB and mercury. These piecemeal efforts, which derive from the media-specific and sometimes activity-specific focus of applicable statutes that address environmental contaminants, will be confounded by conflicting federal, state, or provincial priorities for environmental protection.

For example, attempts to implement pollution prevention protocols for industrial and municipal point source dischargers, either directly or through programs such as the industrial pretreatment program (IPP), would be pursued through the U.S. CWA or through the Ontario Environmental Protection and Water Resources Acts. However, the aggressiveness with which pollution prevention programs are pursued may be dependent upon the priorities of each state or province as it is these jurisdictions that have primacy for implementation of programs such as the IPP. Further, treatment-based actions that are driven by water quality criteria or objectives would be pursued through the same statutes but through different sections as well as different portions of implementing jurisdictions and agencies.

Activities to remediate contaminated sediments would also be implemented through the same statutes but again through different statutory sections as well as different portions of implementing jurisdictions and agencies. Clean-up of contaminated sediments, however, will require pursuit through statutes other than the those that address water pollution. For example, the transport of contaminated sediments will be regulated and perhaps obstructed in the U.S. by the HMTA and other federal statutes as well as by state or local priorities, while destruction of contaminated sediments will be regulated under yet other statutes (e.g. in the U.S. under RCRA or the CAA) with influence from state and local jurisdictions.

Restriction and prohibition of disposal of PCB-containing equipment in landfills would also be pursued through RCRA (with changes or amendments necessary likely at both the state and federal levels) although addressing the destruction of these materials will require not only use of but perhaps changes in the CWA, CAA, TSCA, and other statutes. A ban on the use of mercury as a pesticide would occur through FIFRA or the Canadian Pest Control Products Act although implementation of such a ban may be necessary at the state or provincial level as sufficient political will may not exist at the federal level. Requirements for recovery of products containing PCB or mercury, or requiring elimination of mercury in products such as batteries, would likely be implemented at the state or provincial level since existing federal statutes have not been effective in forcing these kinds of activities.

An immense, and perhaps unrealistic effort will be required to amend and then implement the multitude of federal, state, and provincial legislation to achieve virtual elimination of PCB and mercury. Further effort will be required to coordinate virtual elimination activities under these statutes. Therefore, a new approach to achieve the virtual elimination of PCB and mercury through implementation of the proposed actions presented in this appendix appears necessary. This new approach is necessary in light of the immense effort that would be required to pursue virtual elimination of PCB and mercury through existing legislation, and in light of the low probability of success.

Any new approach must include changes in political and philosophical attitudes toward hazardous chemical management. One of the primary changes must be rejection of the *de minimis* quantity and assimilative capacity paradigms and replacement with a new paradigm for both environmental occurrences of PCB and mercury, and for their occurrence in products and processes. The new paradigm must be based on a recognition that any concentration of...
Appendix A

These conclusions and recommendations were developed by the Virtual Elimination Task Force, based on the content of this appendix.

Appendix A describes a wide range of actions necessary (but not sufficient) to virtually eliminate PCB and mercury from the ecosystem. Virtual elimination of these and other confirmed persistent toxic substances will not occur through reliance solely on treatment and control activities that are applied at the point of release. Prevention must be adopted and rigorously pursued to ensure that no additional quantities of PCB and mercury (those not already circulating in the ecosystem) are created, used, or released to the ecosystem. Current pollution prevention approaches, as they are applied by governments, will reduce, but not eliminate releases to the ecosystem. Concurrently, remediation of contaminated sediment, waste disposal sites, and other in-place sources of persistent toxic substances must take place.

To virtually eliminate PCB, a "banned" substance, the Virtual Elimination Task Force recommends:

20. Governments and industry recover and destroy all existing stocks of PCBs in equipment, cease land disposal, and recover and destroy PCBs in sediment and landfills.

To virtually eliminate mercury, a substance with natural and anthropogenic sources, the Virtual Elimination Task Force recommends:
21. Governments and industry reduce the use of fossil fuels with high mercury content, concurrently implement conservation measures to reduce electric demand and fuel consumption, phase out mercury use in consumer products, as well as mercury-based industrial processes, reduce mercury emissions from smelter operations, and recover (rather than dispose of) mercury in existing consumer and medical products.

For both PCB and mercury, the decisionmaking process presented in Chapter 3 should be used.

REFERENCES


Appendix A


APPENDIX B

CHLORINE: DEVELOPMENT OF A LONG-TERM STRATEGY FOR A BASIC FEEDSTOCK SUBSTANCE

Three Reports
to the
Virtual Elimination Task Force
CHILDREN DEVELOPMENT OF A LONG-TERM STRATEGY
FOR A BASIC MEDICINE SUBSTANCE

Final Report

to the

Victoria Elimination Task Force
Appendix B

CHLORINE: DEVELOPMENT OF A LONG-TERM STRATEGY FOR A BASIC FEEDSTOCK SUBSTANCE

Three background reports were submitted to the Task Force and are reproduced in this appendix:

- A Report on Chlorine to the Virtual Elimination Task Force, by G.N. Werezak. page 33
- Virtual Elimination in the Pulp and Paper Industry, by D.K. Phenicie. page 41
- Case Study: Application of a Virtual Elimination Strategy to an Industrial Feedstock Chemical - Chlorine, by T. Muir, T. Eder, P. Muldoon, and S. Lerner. page 47

The views expressed in these three reports are those of the authors and do not necessarily represent those of the Task Force. The Task Force had difficulty reaching consensus on this issue. There are complex, challenging, and controversial issues that must be addressed in dealing with basic feedstock substances on which key elements of our current lifestyle have come to depend.

At the core of the controversy is the conviction held by some, that so many priority chemicals contain chlorine, that there is justification for eliminating chlorine and chlorine compounds as industrial feedstocks and that essentially, society should avoid the production of all organochlorine chemicals. Others have equally strong convictions that many organochlorine chemicals are valuable and, with appropriate care, can be used safely by society with no adverse effects. There are obviously significant economic and international trade implications.

The fundamental question with regard to chlorine, or indeed other feedstock substances, is where to place the focus to achieve the virtual elimination of persistent toxic substances. The focus can be on:

- Individual products or their uses, such as PCBs, or
- Particular production processes or uses which can lead to formation of persistent toxic substances, such as 2,3,7,8-TCDD, or
- Production or use of a feedstock substance, such as chlorine, or
- Some combination of the above.

Some members of the Task Force believe that action has to be taken now, based on the information available. Other members believe that prior to developing a long-term strategy for feedstock substances such as chlorine or benzene, the Parties should commission an exhaustive investigation that explores all factors and implications related to the proposed sunsetting of chlorine. Such an investigation should be conducted with input and participation from all stakeholders, including industry, environmental and health experts, consumer and labor groups, special interest groups and the general public. That investigation should consider, at a minimum, the following issues, which are flagged in the three background reports that follow:

1) The chlorine “use tree.” What are the various products and uses of chlorine, chlorine-containing and chlorine-derived compounds? Should these uses and compounds be investigated following a use tree approach as described in Chapter 3?

2) Social-economic considerations. What are the social, economic and environmental (including human health) implications of sunsetting uses of chlorine? To what extent is a given use/product essential or important? To what extent is a given use/product consistent with goals of sustainable development? How can negative impacts of change be mitigated?

3) Alternatives. What are the viable alternatives to the use of chlorine, chlorine-containing, and chlorine-derived compounds? Would it be necessary to subject the alternatives to the same criteria used relative to chlorine use? What timeframes are viable for development or selection of alternatives and successful integration of such alternatives into use as feedstocks?

4) Priorities. How should we establish priorities for restricting or eliminating specific chlorine uses, that is, considering factors such as toxicity, exposure, volume released and risk, what uses of chlorine in industrial processes are priorities for sunsetting and by what dates? Which uses of chlorine have the highest priority based on criteria such as persistence and bioaccumulation?

The Task Force believes that, only with the funding of a broad-based consultation program that includes all the stakeholders, can a viable long-term strategy be developed for the possible phaseout of a
basic, feedstock chemical such as chlorine. The Virtual Elimination Task Force recommends:

22. The Parties commission an exhaustive investigation that explores all factors and implications related to the implementation of the proposed sunsetting of a basic feedstock substance such as chlorine.
Appendix B

A REPORT ON CHLORINE TO THE VIRTUAL ELIMINATION TASK FORCE

by George Werezak

July 29, 1993

DISCLAIMER
The views expressed in this report are those of the author and do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission.

FOREWORD
The purpose of this paper is to present the basis for the International Joint Commission to support an exhaustive investigation of chlorine's use as a necessary first step towards determining whether any chlorine uses should be recommended for sunsetting. This investigation should give consideration to the broad range of chlorine's uses and benefits, potential health and environmental risks, the social and economic impacts of sunsetting chlorine's use, and the risks associated with alternatives. The investigation should be based on sound and defensible scientific analysis that addresses each of the areas previously mentioned.

My opinion is based on a continuing review of the economic, environmental, health, legal, scientific, social and technical factors involving society's use and disposal of chlorine and compounds derived from chlorine, and discussions with scientists and technical experts involved with chlorine chemistry. Further, I believe that the current structure of United States/Canadian laws and regulations provides an appropriate legal framework for controlling the use and disposal of chlorine and chlorinated compounds, particularly those that may be determined by scientific analysis to be persistent toxic substances that bioaccumulate. Further, there remains a need for continuing, cooperative scientific dialogue to resolve questions regarding the risks posed by some applications of chlorine and chlorination chemistry, as well as the risks posed by potential alternatives.

CHLORINE THE ELEMENT
Chlorine, a nonmetallic, naturally occurring element, is a member of the halogen family. The halogen family comprises five elements -- fluorine, chlorine, bromine, iodine and astatine. Chlorine's atomic number is 17 and atomic weight is 35.45.

Liquid (elemental) chlorine is a clear, amber fluid that vaporizes readily under ambient conditions to a greenish yellow gas that is roughly 2.5 times as heavy as air. Because it is very reactive, chlorine combines readily with other inorganic and organic elements as soon as it is produced (unless restricted from doing so), so it is not commonly found in its elemental state. Chlorine, as part of stable compounds (usually chlorides), comprises roughly 0.03% of the earth's crust, 2.0% of all ocean waters and 0.17% of the total weight of the human body (1,2).

CHLORINE AND CHLORINE-CONTAINING COMPOUNDS IN NATURE
Chlorine-containing compounds are not solely human inventions; they are common in nature. They are part of life itself and are essential to the workings of many living organisms, including humans. Chlorine and chlorinated compounds exhibit no toxic or other harmful properties that are unique among the remaining elements (3,4).

Until recently, it was believed that nearly all chlorine-containing compounds were humanmade. Improvements in our ability to detect and measure minute quantities of chemicals have demonstrated that hundreds of chlorine-containing compounds occur naturally in many settings (3,5).

Natural sources of chlorine-containing compounds include the oceans (chlorides), volcanic eruptions (hydrochloric acid), forest and grass fires (organic chlorine compounds), and the biosynthesis by a wide range of simple and complex living organisms -- fungi, bacteria, higher plants, marine organisms and humans -- in amounts that often dwarf humanmade sources.

The structure of these compounds ranges from simple carbon-based gases such as methylene chloride and chloroform to unsaturated lipids to complex molecules with multiple aromatic rings. This diverse array of compounds is produced by natural catalysts (enzymes) within plant and animal cells. The purpose of these enzymes appears to be to produce chlorine-containing compounds for direct use by the organism, for intermediates that react further to form...
end products needed by the organism, and to defend the cell or body by altering bacterial molecules by reacting them with the chlorine compound (3).

CHLORINE AND CHLORINE CHEMISTRY PROCESSES AND PRODUCTS

Making chlor-alkali chemicals is among the most basic of all chemical processes. Electricity is used to separate salt water into chlorine and its coproducts sodium or potassium hydroxide and hydrogen (6). From this relatively simple beginning, the chlorine molecule is estimated to be involved in more than half of all commercial chemistry. Chlorine's coproducts -- sodium and potassium hydroxide -- are widely used in every branch of industry, including mining, textile production, food processing, the production of soap and cleaning agents, and water and wastewater treatment. Thus, the products of chlorine chemistry - chlorine, products containing chlorine, and products derived from chlorine -- directly and indirectly provide extensive social and economic benefits.

A recent conservative analysis of the major uses (90% of consumption) of chlorine and their potential alternatives revealed that United States and Canadian consumers annually enjoy more than $100 billion in annual savings (benefits) from the use of chlorine and products based on chlorine chemistry, rather than the use of alternatives. In the Great Lakes region, these savings amount to more than $20 billion per year (7).

Chlorine has become important in thousands of applications because of its particular physical and chemical properties. There are limited instances where other elements can replace chlorine with modest incremental cost or performance penalties, but in most instances it would be difficult to achieve the desired performance in a cost-effective manner without chlorine. The use of alternate processes or materials (if they exist) would entail significant economic and social losses and cost increases, along with the alternative's associated human health and environmental risks.

Even though chlorine is used in almost all sectors of our economy, most consumers do not realize how broadly this element touches their daily lives because most are only aware of its direct uses. In many cases, chlorine is not contained in the end product, but it is used as an intermediate raw material, as a catalyst, or as part of a larger manufacturing sequence where chlorine may or may not end up in the final product. The properties that make these products useful to consumers depend on the chlorine content.

Direct consumption is one of three distinct ways in which society uses and benefits from chlorine. Chlorine is also incorporated into other consumable products, providing them with specific, desirable characteristics, and it is used as a facilitator in the manufacture of thousands of other products.

Consumers generally identify chlorine's role in those uses that have direct applications, such as disinfecting public water supplies and swimming pools and its use as a key component in laundry bleaches. It is also used to destroy disease-carrying organisms present in effluents from wastewater treatment plants. Another direct use of chlorine is in the pulp and paper industry, where it is applied in the bleaching cycle to produce pulp for high-quality paper.

Polyvinyl chloride (PVC or vinyl) manufacturing constitutes the largest single use of chlorine. This versatile plastic is found in a wide range of household consumer products such as luggage, raincoats, furniture and packaging. PVC also is widely used in automotive applications for seat covers, floor mats, and dashboards; building and construction applications for such products as sewer and drain pipe, vinyl siding, gutters, windows and door frames, flooring, and electrical wire insulation also depend on PVC. In all these applications (and in numerous others), PVC products provide long life, strength, fire retardance, weight reductions, energy savings, ease of fabrication, and other desirable properties.

In many cases, chlorine-containing products are used in such a way that the consumer is not likely to be aware that the final product or service depends on chlorine. Chloropene is used to make fan and conveyor belts, and other heat- and oil-resistant products in automotive and industrial applications. Chlorinated solvents are used in dry cleaning and to clean metal and other parts during their conversion to consumer goods ranging from automobiles to electronics to photographic film. In the same way, reformulated chlorine-containing crop protection chemicals such as herbicides, fungicides, and insecticides are applied to increase yields and reduce losses caused by pests. Further, today's crop protection chemicals are far less persistent in the environment than those utilized in the past.

Chlorine also is used in thousands of applications where it is not a part of the final consumer product, where it plays the facilitator role. The versatility of the chlorine-containing intermediate materials is their key importance because the production of other products would be far more costly to manufacture without chlorine chemistry.

Perhaps the most notable example of chlorine's role as a facilitator is its use in pharmaceutical products. Far less than 1% of all chlorine is used in pharmaceutical product manufacturing, but nearly 85% of these products are based on chlorine chemistry. Only 20% of these drugs actually contain chlorine as an active ingredient in the final product. Most often, the chlorine molecule is replaced at an intermediate processing step by another element. The complex chemical structures that are necessary for the therapeutic functions of these drugs are
extremely difficult to produce without chlorine chemistry.

Chlorine-based catalysts represent another major category of chemical facilitator. Chlorine provides the most cost-effective means of promoting high-performance chemical reactions. Some important uses of chlorine-based catalysts are in the manufacture of polyethylene and polypropylene resins, which are used in large quantities to make carpeting, rope, film, packaging, appliance manufacturing, and automobiles. Catalysts containing chlorine are used in the manufacture of ethylbenzene, which is used as a raw material for polystyrene, other styrene polymers, and unsaturated polyester resins that are fabricated into a myriad of consumer products.

Chlorine chemistry is also involved in the manufacture of other commonly used plastic products, including polycarbonate and fluoropolymer resins. Polycarbonate resins are used in such products as compact disks, shatterproof car headlamps, and bulletproof glass for buses, trains and airplanes. Fluoropolymers are used to produce nonstick cookware and industrial coatings that are designed to resist harsh and corrosive environments.

Other examples of chlorine’s versatility include the manufacture of propylene oxide, which is used in food additives and polyurethanes -- foam cushions, automobile bumpers, and coatings and adhesives. The manufacture of all silicone products, which include silicone coatings and sealants, fluids for automotive application, resins for medical/surgical devices, and components of silicon chips -- the basis for all modern consumer and industrial electronics -- depend on chlorine chemistry.

The products and process uses mentioned above represent sectors of the United States and Canadian economies with sales that range from the hundreds of millions to the tens of billions of dollars. These sales are one measure of the value consumers assign to products and uses that depend on chlorine and chlorine chemistry. Underlying these sales are the millions of jobs tied directly and indirectly to the products of chlorine chemistry (7).

HAZARDS AND RISKS ASSOCIATED WITH CHLORINE PRODUCTS/BYPRODUCTS

The potential for any chemical to produce an adverse effect on humans or impair the environment should be determined by a systematic reference to risks on the basis of exposure. Since exposure is a requirement for an effect to occur, exposure is more important than the toxicity of a substance. Key elements of exposure include: environmental loading rates, concentration, daily intake and environmental fate processes such as biodegradation, transformation, partitioning and transport. Since all these parameters (and others) vary with each substance, there is no scientific justification for labelling all chlorine-containing compounds as presenting comparable risks to human health and the environment (8).

The evaluation of the potential for adverse impacts of chemicals on the environment or human health must be based on established risk assessment procedures. The fundamental principle of such assessments is that the magnitude of the response of an organism to a chemical increases with increasing dose of the chemical to the organism.

The toxicity of a chemical is governed by its physical and chemical properties, which determine how the chemical behaves in the environment and in biological systems. The addition of chlorine per se to a molecule does not necessarily increase the toxicity of a chemical. Available scientific evidence indicates that any current potential risk associated with chlorinated compounds must be evaluated in light of existing toxicity and exposure potential of chlorinated compounds presently in use.

For example, virtually all the chlorinated alkanes and alkenes, and most of the lower chlorinated monoaromatics, in present use have relatively short half-lives in water, air, sediment and biological tissues and therefore do not accumulate in these media. Such compounds include chloroform, methylene chloride, dichloroethane, trichloroethylene, chlorobenzene, dichlorobenzene, dichlorophenol, and many other chlorinated organics. They are critical to the manufacture of many important end products. Body burdens of such chlorinated organic chemicals do not accumulate to toxic concentrations because they are rapidly metabolized and excreted by organisms in the environment. Thence, they do not accumulate to any significant extent in the environment or in biological tissues.

Studies on chlorinated compounds presently in use indicate that at concentrations detected in the environment, wildlife and human exposures are far below those exposures noted in animal studies to produce toxic effects. For example, a number of well conducted mammalian and aquatic toxicity studies have been conducted on the alkanes (e.g. chloroform), alkenes (e.g. trichloroethylene) and lower chlorinated monoaromatics (e.g. dichlorophenols and dichlorobenzenes) which clearly indicate that environmental concentrations of these chlorinated organic chemicals presently in use are well below levels which induce adverse effects (8).

Any adverse effects noted in wildlife in the Great Lakes region have been associated with a limited subset of chlorinated compounds, such as PCBs, DDT and several other cancelled pesticides. The distribution of these chemicals in the environment was due to their historical use or unintended generation. No
such adverse effects have been reported for the chlorinated alkanes, alkenes, or lower chlorinated monoaromatics, nor would any be expected based on their inherent toxicity, fate and partitioning in the environment. The toxicological effects observed in some wildlife relate to past exposures to select chlorinated compounds. This pattern is not reflective of use patterns or environmental loading rates of chlorinated compounds in use in the Great Lakes region today (8).

The suggestion that some chlorinated compounds have induced adverse effects to humans in the Great Lakes is not supported by available scientific information. A number of epidemiological studies that have examined mortality rates, incidence of birth defects, reproductive outcomes, morbidity and other endpoints, have consistently found no differences in comparison with control populations (see, for example, References (9,10)).

One study has suggested possible effects in children of mothers consuming (on a regular basis) fish containing low levels of PCBs that were assumed to have originated from Lake Michigan (11-13). This report’s findings have not been corroborated by followup studies and the study did not control for possible confounders such as smoking and drinking alcohol (14,15). Presently, there is no valid evidence that chlorinated organic compounds have had an impact on human health in the Great Lakes region. Further study on the possible effects of environmental exposures to PCBs may be warranted, specifically areas that have been delineated as “toxic hotspots.”

In summary, a careful evaluation of the toxicology, environmental fate, and partitioning characteristics of chlorinated compounds must be undertaken to put in perspective the potential environmental and human health risks associated with concentrations of these compounds in the environment. Generalizations about the potential adverse environmental consequences of chlorinated compounds should not be made on the basis of adverse effects observed with a few selected substances.

IMPACTS AND TRENDS OF CHLORINE/CHLORINATED COMPOUNDS ON THE GREAT LAKES

Available scientific evidence indicates that the Great Lakes ecosystem has shown measurable recovery as a result of actions taken to reduce releases and to restrict specific uses of chlorine and chlorinated compounds. A number of recent studies have shown that with decreasing concentrations of chlorinated compounds of concern, previously affected bird species in the Great Lakes ecosystem have made significant recoveries (see, for example, References (16-18)).
1990 Report to Congress (20), however, out of 17 pesticides, PCBs and chlorinated benzenes, only PCBs and hexachlorobenzene were found in significant concentrations throughout the open water of the lake. Moreover, concentrations of PCBs, DDT and other organic compounds have not increased in the lake since monitoring began in 1977.

In Lake Ontario, data presented in the 1988 and 1990 Reports to Congress on sediment and sport fish indicated declines in the uptake of PCBs, DDT, mirex, and chlorinated benzenes between the early to mid-1970s and 1980. Other data substantiate this finding by demonstrating significant declines since 1975 in PCB and DDT residue in spottail shiners, collected at the outlet of the Niagara River.

VIRTUAL ELIMINATION STRATEGIES FOR CHLORINE/CHLORINATED COMPOUNDS

Under existing United States federal and state laws and regulations, significant steps have been taken and continue to be taken to reduce inputs of potentially persistent and toxic chlorinated compounds into the Great Lakes. These laws also provide a proper framework for further actions to achieve additional reductions, where sufficient scientific data exist to demonstrate that a particular use or release of a substance poses an unacceptable risk to human health or the environment.

Releases of chlorinated compounds to the environment are regulated under several statutes, including the Clean Water Act (CWA) (21), Clean Air Act (CAA) and the Resource Conservation and Recovery Act (RCRA) (22). Section 307 of the CWA includes 32 chlorinated compounds on the list of 66 priority toxic pollutants that are regulated. The recent CAA amendments of 1990 include a total of 189 hazardous air pollutants, of which 58 are chlorinated compounds.

In addition, uses of certain specific chlorinated compounds have been restricted or banned under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (23) and the Toxic Substances Control Act (TSCA) (24). These compounds, which include PCBs, DDT, dieldrin, chlordane, and toxaphene, have been properly singled out for restriction because of their known persistence in the environment and adverse impacts on aquatic life and wildlife.

Non-regulatory initiatives, such as U.S. EPA's 33/50 program, are also reducing the release of some chlorinated compounds into the environment. Product stewardship is becoming a prevalent practice by industry to manage products through all stages of their life cycles in a manner that continuously improves protection of human health and the environment. Together, these regulatory programs and voluntary initiatives have resulted in significant reductions in inputs of chlorinated compounds to the Great Lakes and will continue to achieve further reductions.

The results of regulation of emissions and wastes coupled with the product stewardship efforts of industry have and will continue to insure that exposures to toxic materials are reduced. When there is adequate data to demonstrate likely adverse effects, the government has authority, through TSCA and FIFRA to regulate chemical use. These mechanisms correctly provide for consideration of health and environmental effects, magnitude of exposure, societal benefits, and economic consequences associated with chemical uses. Bans or restrictions on chemicals or products that do not take into account these considerations are arbitrary and not supportable.

In new decisions to ban it is imperative that the government use risk/benefit assessments for particular uses. In fact, it is impossible to determine the risk of a particular product or chemical without considering its use. Risk assessments require the determination of the pathways of exposure and the duration and likelihood of exposure. The use of the product will define the exposure pathways and the potential for exposure. Use of hazard analysis alone ignores magnitude of exposures.

Target lists developed from an evaluation of the hazards of a chemical are too simplistic and can lead the public to make emotional decisions to ban a product without consideration of benefits and risks and without consideration of the benefits and risks of substitute products. Any listing criteria that are developed should be tied closely to full risk/benefit assessment utilizing sound scientific principles. Additionally, there should be evidence that existing ambient concentrations of a chemical are posing a potential adverse effect to the environment before a chemical is targeted.

Outlined below is a description of the regulatory framework already in place in the United States to regulate releases and uses of persistent and/or toxic substances. Canada has a comparable legal framework for regulating toxic materials, which is not presented here. Industry's responsibility to properly manage these materials through product stewardship also is presented.

RELEASES OF CHLORINE/CHLORINATED COMPOUNDS

Significant reductions in releases of chlorinated compounds to water, air and other media have been achieved and continue to be achieved as a result of existing regulatory programs under the CWA, CAA, and RCRA and voluntary initiatives. Additional regulations are still in development while others have
only begun to be implemented. Thus, further reductions in loadings of chlorinated compounds to the Great Lakes will occur in the years ahead.

For example, since 1972 when the CWA was passed, U.S. EPA has established best available technology (BAT) requirements for more than 50 industrial categories. These requirements specify technology-based standards for effluent discharges to surface water, including the Great Lakes and their tributaries. According to information cited in U.S. EPA's recent proposed Lakewide Management Plan (LaMP) for Lake Michigan, greater than 70% reductions have been achieved for most constituents from the six major industrial sectors in the Great Lakes regulated by BAT guidelines. BAT guidelines are still under development for other industrial categories. Additional water-quality-based effluent discharge limits are being incorporated into many industrial discharge permits to further reduce the amount of toxics released into the Great Lakes. Recent regulations on stormwater from municipal and industrial activity will reduce even further these inputs.

Specific guidelines are under development which will establish uniform, stringent water quality criteria and procedures for the Great Lakes (25). States will be required to adopt standards consistent with the guidelines in the next two to three years. These new water quality standards and procedures will, in turn, be incorporated into discharge permits in the form of more stringent limits on the discharge of persistent and toxic substances. The impact of these ongoing regulatory activities on water quality in the Great Lakes will be realized over the next few years.

Atmospheric transport and deposition as well as resuspension of contaminated sediments are believed to provide the primary pathways for transport of many of the pollutants of concern in the Great Lakes. Data compiled under the CAA of 1990 show that atmospheric loadings to the Great Lakes are declining. Recent atmospheric loadings of PCBs, DDT and other chlorinated compounds are less than in previous decades. These loadings will further decrease as a result of new regulatory programs under the CAA. For example, U.S. EPA currently is establishing maximum achievable control technology (MACT) requirements for hazardous air pollutants. The MACT regulation for the synthetic organic chemical manufacturing industry (SOCMI) was among the first rules proposed to regulate releases of these hazardous air pollutants. When final rules are in place in 1993, U.S. EPA estimates that releases of hazardous air pollutants from SOCMI facilities will be reduced by 80% nationwide.

U.S. EPA also is working on criteria and a strategy for managing contaminated sediment. This strategy includes components for preventing future contamination of sediments and remediating existing contaminated sediment sites. Criteria are being developed for use in identifying contaminated sediments which may be causing adverse impacts to human health and the environment. Existing U.S. EPA data indicate that sediment contamination is mainly confined to limited number of locations in the Great Lakes, typically downstream of urban, industrial and agricultural areas and are generally the result of past practices. Remediation of these sediments may be necessary to reduce this source of loadings of persistent toxic substances, where they are causing adverse impacts on human health or the environment. In many cases, the preferred remediation approach will involve natural cleanup processes such as biodegradation and natural sediment capping in order to avoid the resuspension of contaminants into the water column.

EXISTING USE RESTRICTIONS/BANS

Restrictions and registration cancellations under FIFRA and TSCA have significantly reduced loadings of persistent toxic substances into the Great Lakes. For example, PCBs and DDT, which are responsible for the majority of fish advisories in the Great Lakes, have been restricted or banned, because of their known persistence in the environment and their association with adverse impacts on aquatic life and wildlife.

PCBs, which were commercially manufactured from 1929 until 1976, are banned, although quantities still remain in transformers, landfills, and sediments. DDT/DDE is one of four pesticides that have been cancelled because of their persistent, toxic effects. (The others are dieldrin, chlordane, and toxaphene). Although these banned and restricted substances continue to be detected in Great Lakes waters and fish, their inputs have been significantly reduced from historic levels.

Data on sources of remaining loadings of these restricted compounds are limited, but information suggests that air transport and contaminated sediments are presently the largest sources of input to the Great Lakes. Additional ongoing efforts, including "clean sweep" programs to collect and destroy existing stockpiles of banned substances, will be helpful in further reducing levels of these substances in the environment. Remediation of contaminated sediment also may be necessary to achieve further significant reductions in levels of these persistent compounds in the Great Lakes ecosystem in a reasonable timeframe.

PRODUCT STEWARDSHIP/RESPONSIBLE CARE

Many segments of industry, particularly the chemical industry, are committed to controlling hazards and managing risks associated with chlorine and chlorinated products through a process known as
product stewardship. Product stewardship is a system for using and managing products through all stages in their life cycle in a manner that continuously improves protection of human health and the environment. The process applies to both new and existing products. It begins with research and development and continues through commercialization, disposal, and environmental fate.

Product stewardship is a shared responsibility that covers all stages of a product’s life. This includes full consideration of methods to increase protection of human health and the environment in terms of: raw materials use, storage and transportation; manufacturing processes; providing a safe and healthy workplace; packaging; product use and transportation; and educating product users about safe and efficient use and disposal.

Product stewardship/responsible care is initiated by industry, typically at the corporate level, in conjunction with business planning. Risk characterization, screening, and management are the key vehicles for product stewardship.

CONCLUSION

The use of chlorine and chlorine-derived materials is integral to the social and economic well-being of the United States and Canada. Annually, these materials provide more than $100 billion of benefits (savings) to the people of the United States and Canada, with more than $20 billion in benefits accruing to people in the Great Lakes region.

Any policy decision regarding a ban on chlorine’s use that does not consider and evaluate the consequences of that action would be ill-advised and would likely have a very damaging effect on the economic and social welfare of the United States and Canada.

REFERENCES


VIRTUAL ELIMINATION IN THE PULP AND PAPER INDUSTRY
A Report to the Virtual Elimination Task Force

by D. K. Phenicie

January 7, 1993

DISCLAIMER
The views expressed in this report are those of the author and do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission.

VIRTUAL ELIMINATION IN THE PULP AND PAPER INDUSTRY

In its Interim Report, the Virtual Elimination Task Force expressed particular concern over the use of chlorine by the pulp and paper industry. It is now clear that as a result of process modifications developed and implemented in the last six years, the industry has dramatically reduced discharges of persistent chlorinated compounds, including dioxin.

Pulp bleaching now accounts for less than 1% of the known sources of dioxin and furan compounds released into the environment. The industry has also significantly reduced discharges of other chlorinated organic compounds. Accordingly, there is no reason to single out the pulp and paper industry for differential treatment in the Final Report.

Studies show that discharges from well controlled pulp mills do not result in toxic effects in the environment. For example, experimental stream studies in the United States and a recent study at a Canadian mill (all published in the last two years) showed no significant effects on the health of fish or aquatic organisms. Whole effluent toxicity testing, as well as water quality and technology-based regulations, assure that bleached mill effluent is not resulting in any adverse effects on the environment.

Moreover, the pulp and paper industry can achieve virtual elimination of discharges of persistent toxic compounds without eliminating chlorine completely. The Great Lakes Water Quality Agreement calls for virtual elimination of "persistent toxic substances," not the universe of all chlorinated compounds. The industry has demonstrated that it is achieving virtual elimination of discharges of tetrachlorodibenzo-p-dioxin (TCDD), tetrachlorodibenzo furan (TCDF), and other persistent compounds of concern through process modifications that reduce, but do not totally eliminate, all forms of chlorine in the pulp bleaching process.

Accordingly, the Task Force can now revise its recommendations [in its Interim Report] to omit particular targeting of the pulp and paper industry, and need not call for sunsetting chlorine usage in the industry. The Final Report should instead focus on larger contributors of the specific persistent toxic compounds of concern.

DISCOVERY OF DIOXIN ASSOCIATED WITH PULP MILLS

Although the pulp and paper industry has used chlorine to bleach pulp since the 1930s, the fact that dioxin and furan compounds are produced as unwanted byproducts from chlorine bleaching is a relatively recent discovery. When improved analytical techniques measuring in the parts per trillion and quadrillion range enabled the detection of dioxin at these minute levels, the industry moved promptly to identify and dramatically reduce the sources of dioxin discharges.

Immediately following the discovery of dioxin associated with pulp mills, the United States industry began cooperating with the U.S. Environmental Protection Agency (EPA) and other agencies. In 1986-87, U.S. EPA and the industry conducted a pilot study of five mills. Results pointed to an association between dioxin formation and the bleaching process.

The industry and U.S. EPA then expanded their study to include all 104 bleached pulp mills in the United States. The results of that study, released in 1989 and 1990, confirmed the initial findings. At the time of the study, the total amount of TCDD equivalents released in a year from all 104 mills was 41 ounces.

CURRENT DIOXIN CONTRIBUTION

As a result of intense and voluntary efforts by the industry in a very short time, fewer than eight ounces of dioxin (toxic equivalents) are now generated annually from United States pulp bleaching nationwide -- approximately 1% of all known sources of dioxin in the United States. Hence, for all the
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indications of either tumors or lesions in fish exposed to effluent. (See References (2,3)).

In a recent study conducted in a riverine ecosystem in western Canada, exposure to bleached mill effluent did not have discernible impacts on either fish populations or individual fish health (See Reference (4)). No significant differences in histopathology, serum chemistry, or hematology were consistently observed for the target fish species compared to a reference river system. In sum, there were no impacts at lower and potentially sensitive levels of biological organization (morphological, physiological, and biochemical) at the levels in this study. The study involved a river that had received biologically treated effluent for 16 years. The authors conclude that rather than body burden of organochlorines, "other factors unrelated to the bleaching system such as operational stability and biological wastewater treatment may be as or more important in determining environmental impact."

OTHER CHLORINATED COMPOUNDS IN BLEACHED MILL EFFLUENTS

The Task Force has focused particular attention on TCDD and TCDF in discharges from the pulp and paper industry. However, these compounds are no longer measurable in the effluents of the majority of mills. Other persistent toxic compounds that the Water Quality Board has targeted (e.g. pesticides, PCBs) are not associated with pulp bleaching.
While there are other chlorinated compounds in bleached mill effluents, only a fraction of a percentage of them are of potential environmental significance. Only certain persistent compounds -- not all chlorinated organic compounds -- are of concern.

"AOX" (for "total adsorbable organohalides") is a measure of all of the chlorinated organic compounds in bleach pulp mill effluents. AOX does not measure or represent toxicity. Rather, of the AOX:

- About 90% of the chlorine used in pulp bleaching ends up as common salts.
- Less than 10% binds to organic material in the pulp to form chlorinated organic compounds.
- Only about 1% of the chlorine forms potentially bioaccumulable compounds.
- And only 0.1% forms highly lipophilic (fat soluble) and bioaccumulable compounds.

Since the vast majority (99.1%) of chlorinated organics associated with pulp bleaching are not readily absorbed by the human body or aquatic organisms, total elimination of all chlorinated compounds would carry little or no environmental benefit.

Regulations to address those compounds of potential environmental significance will be proposed by U.S. EPA this year. U.S. EPA will be imposing updated technology-based effluent guidelines as well as new maximum achievable control technology (MACT) limitations on air emissions from the pulp and paper industry, covering the specific chlorinated compounds U.S. EPA has determined to be significant. The Great Lakes Initiative currently under development in the United States will undoubtedly impose further restrictions. All United States mills already have effective secondary (biological) wastewater treatment.

Canadian standards require secondary treatment. In addition, pulp and paper effluent standards under development in Canadian provinces -- through the National Pollutant Release Inventory and Accelerated Reduction/Elimination of Toxics program -- will offer similar protection with respect to toxics.

These restrictions, along with the existing regulations and the voluntary process modifications already made by the pulp and paper industry, assure that discharges of the persistent compounds of concern will be virtually eliminated.

In addition, United States mills routinely perform acute and chronic toxicity tests on their whole effluent to assess potential toxicity. Similarly, Canadian mills routinely perform acute toxicity evaluations and are beginning to do chronic studies. Thus, the effect of all chlorinated compounds in bleached mill effluents is monitored through direct biological testing of the actual effluents.

REDUCING DIOXIN FORMATION

The virtual elimination of dioxins, furans and other chlorinated organic compounds of concern has been accomplished through intense research and process modification efforts since the discovery of dioxin in the paper industry six years ago.

Scientists have identified a number of process modifications that can reduce dioxin. These dioxin control measures also reduce discharges of other chlorinated organic compounds (See Reference (5)).

These modifications have been put into effect, voluntarily, over the last several years (many coming on line since the Interim Report). While many aspects of dioxin formation are highly mill-specific, among the significant process modifications that have been used by members of the industry are:

- Substitution of chlorine dioxide, which has less available chlorine, for some or all of the molecular chlorine used in the bleaching process; this step alone has in many cases reduced dioxin discharges below measurable levels.
- Changes in the bleaching sequence or methods of chemical addition during bleaching.
- Elimination of the use of certain defoamers or other inputs to the process that contain dioxin precursors.
- Use of oxygen and/or hydrogen peroxide as supplements to chlorine in the bleaching process.
- Use of chemical or process changes (such as oxygen delignification, extended cooking, improved washing) or other steps for removing lignin in pulp so that less bleaching is required.

Using these methods, mills have been able to virtually eliminate dioxin without having to phase out the use of chlorine completely. Today, dioxin is not measurable in the effluents at more than three-quarters of the mills in the United States. Other mills will complete their modifications soon.

ECONOMIC IMPACT OF PROCESS MODIFICATIONS

These changes have not been without substantial cost. The United States industry estimates that it has already spent over $1 billion implementing these changes in the very short time since dioxin was attributed to the pulping process.
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More work is underway. It is now clear that virtual elimination is being achieved in the pulp and paper industry without the elimination of all forms of chlorine. Total elimination of all forms of chlorine would be prohibitively costly, without conferring additional benefits beyond what other process modifications can achieve.

In a paper presented at a recent U.S. EPA Pollution Prevention Conference, Drs. Phillips, Renard and Lancaster provided cost estimates for further reductions in chlorine usage (6). For cost analysis, they started from a baseline that takes into account that mills are already using a bleaching sequence with reduced chlorine (50% substitution of chlorine dioxide for chlorine in the first stage of bleaching, and 100% chlorine dioxide in the final stages).

The base case results in non-detectable levels of TCDD and TCDF in mill effluents (at a 10 ppq detection limit). The baseline case also represents a 36% reduction in AOX, which as noted above refers to all chlorinated organic compounds, not just the persistent compounds of concern.

Phillips et al. estimated costs for four additional scenarios:

- The first scenario is 100% substitution of chlorine dioxide for chlorine. For the United States industry, this would require an additional $1.2 billion in capital costs beyond the cost for 50% substitution, and $203 million per year in additional operating costs. This scenario would move the total reduction in AOX from the 36% in the base case to 79% of the starting levels.

- The second scenario involves the addition of an oxygen delignification step prior to bleaching, along with 100% substitution of chlorine dioxide for chlorine. The cost here jumps very substantially: $6.9 billion in capital costs for the United States industry, and an additional $83 million in operating costs beyond the base case. This additional investment results in an overall reduction in AOX of 88% from prior levels -- only a small increment beyond the considerably less costly scenario that achieved an 79% reduction.

- A third scenario is the use of oxygen delignification and an ozone stage, still with the use of chlorine dioxide. (The ozone bleaching is just beginning to be tested commercially.) Capital cost skyrocket: an additional $9.6 billion beyond the base case investment. The additional benefit conferred by the $9.6 billion cost is moving to 97% reduction in AOX levels compared to the starting AOX levels. (This additional capital investment is about $3 billion more than the second scenario, which achieves an 88% reduction.)

- A fourth possible scenario is the hypothetical elimination of all chlorine compounds as well as molecular chlorine, instead using oxygen delignification, ozone and peroxide. This has not yet been commercially demonstrated. Projected capital costs equal that of the third scenario -- about $9.6 billion -- but with additional annual operating costs of $421 million beyond the operating costs of the 50% substitution base case.

See Table B-1 for details.

These are staggering costs, for little or no additional benefit to the environment. (As noted, AOX reductions are not a meaningful measure of toxicity. The Task Force is concerned with persistent toxic compounds, not all chlorinated compounds. Thus, AOX reductions overstate any environmental benefit.)

Moreover, these costs are for just the United States pulp and paper industry, which now accounts for less than 1% of the known sources of dioxin released to the environment in the United States. Costs at Canadian mills also must be taken into account and on a per-mill basis are likely to be as much or greater than the United States costs. One estimate has put costs for Ontario mills alone at $1.2 billion.

The United States pulp and paper industry is a large employer -- employing over 700,000 people in the United States, where it is the 14th largest employer, with paper products accounting for about 1% of the 1989 United States gross national product. In Canada, the industry is an even more significant part of the economy. Hence, the economic impact of expenditures for sunsetting chlorine in the pulping process goes beyond the capital and operating costs shown here.

In short, the complete elimination of all forms of chlorine would impose a prohibitive cost, with little or no environmental benefit.

IMPORTANCE OF CHLORINE IN THE PULPING PROCESS

The public health benefits of chlorine are well known. Its use in manufacturing food, medicines, paints, perfumes, automobiles, clothing and electronics is less familiar.

Chlorine in some form is important to the manufacture of bleached pulp for a variety of reasons unrelated to cost:

- It produces strong, bright, white paper for optimum contrast with the inks used in writing paper and printing materials.
Table B-1
Costs of Process Modifications in Addition to Investment in Base Case

The estimated costs to implement further process modifications to reduce chlorine usage at all United States pulp mills are shown below. They are taken from Reference (6).

The cost analysis starts from a baseline that takes into account that mills are already using a bleaching sequence with reduced chlorine. Over $1 billion in capital costs has already been spent on process modifications to achieve the base case.

The "benefit," given as the percentage reduction in AOX, is also shown. The base case results in non-detectable levels (at 10 ppq) of TCDD and TCDF in mill effluents, and represents a 36% reduction in AOX. Note that AOX refers to all chlorinated organic compounds in the effluents, not just the persistent toxics. Thus, there is less benefit than would appear from these figures.

<table>
<thead>
<tr>
<th></th>
<th>ADDITIONAL CAPITAL COSTS</th>
<th>ADDITIONAL ANNUAL OPERATING COSTS</th>
<th>TOTAL AOX REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case (est. to date)</td>
<td>$&gt;1,000,000,000</td>
<td></td>
<td>36%</td>
</tr>
<tr>
<td>1) 100% ClO2 substitution</td>
<td>1,248,900,000</td>
<td>203,100,000</td>
<td>79</td>
</tr>
<tr>
<td>2) oxygen delignification</td>
<td>6,915,200,000</td>
<td>83,900,000</td>
<td>88</td>
</tr>
<tr>
<td>3) oxygen delignification, ozone</td>
<td>9,585,600,000</td>
<td>(114,500,000)</td>
<td>97</td>
</tr>
<tr>
<td>4) no chlorine of any type background</td>
<td>9,585,600,000</td>
<td>421,200,000</td>
<td></td>
</tr>
</tbody>
</table>

Base Case: substitution of 50% chlorine dioxide for chlorine in the first bleaching stage, followed by oxygen and peroxide extraction and two 100% chlorine dioxide stages.

1) 100% chlorine dioxide substitution in the first stage, oxygen and peroxide extraction, and further chlorine dioxide stages
2) Addition of oxygen delignification prior to bleaching, 100% chlorine dioxide substitution in bleaching, oxygen and peroxide extraction, and further chlorine dioxide stages
3) Addition of oxygen delignification prior to bleaching, ozone bleaching, oxygen and peroxide extraction and 100% chlorine dioxide stages
4) No chlorine or chlorine dioxide, use oxygen delignification, ozone and peroxide (not commercially demonstrated)

- It prevents paper from discolouring in storage and yellowing when exposed to sunlight; this is important for recordkeeping and archiving books and documents.
- It removes bark, wood residue and other impurities that blemish paper.
- It eliminates fatty acids, resins and other substances that can cause bad odours and taste in milk and other food products packaged in paperboard products.
- It improves absorption, strength and softness, important characteristics for products such as tissues, napkins, towels and diapers.

In short, the use of chlorine enables the industry to produce paper products with these important attributes. The totally chlorine free processes being investigated have not been able to produce the full range of products with these characteristics. (In addition, the energy and environmental impacts of totally chlorine free processes have not been evaluated.)

NO NEED FOR TARGETING THE PULP AND PAPER INDUSTRY

The pulp and paper industry has demonstrated that it is achieving virtual elimination -- voluntarily, at great expense, and without having to eliminate all use of chlorine compounds.

Thus, there is no rational basis for singling out the pulp and paper industry, or for banning the use of all forms of chlorine in the pulping process, when virtual elimination is being achieved through other process modifications.
REFERENCES


INTRODUCTION: THE COMMISSION'S POSITION

The Virtual Elimination Task Force was charged by the Commission to investigate means of implementing the Great Lakes Water Quality Agreement's requirement that inputs of persistent toxic substances into the Great Lakes Basin Ecosystem be virtually eliminated. The purpose of this report to the Task Force is to recommend a strategy to achieve virtual elimination of persistent chlorinated organics, a class of chemicals that dominates both the list of 11 Critical Pollutants and the Water Quality Board's (WQB) 1986 Working List of Chemicals in the Great Lakes Basin (1).

This class, also called organochlorines, is defined as those compounds in which chlorine is bound to carbon-based organic substances. When referring to compounds containing carbon and chlorine or one of the other halogens (fluorine or bromine), this class is sometimes referred to as halogenated organics. Chlorinated organics are produced intentionally as thousands of chemical products (e.g., pesticides, plastics, and solvents), and as thousands of unintentional byproducts of industrial processes that use chlorine or other organochlorines (e.g., in pulp bleaching, waste incineration, or chemical manufacturing).

The weight of evidence, summarized in "The Injury" section of the Commission's Sixth Biennial Report (2), clearly links persistent toxic substances, particularly organochlorines, in the Great Lakes to injury, disease, and death in a variety of life forms, including humans. This information is also summarized in Appendix D. Of the 11 Critical Pollutants for which the evidence of large-scale effects is strongest, eight are organochlorines. Of the 362 on the WQB's list of chemicals that have been found in the Great Lakes, about half are organochlorines. The Agreement requires that virtual elimination be achieved for these chemicals, if they are determined to be persistent toxic substances.

In the Task Force's 1991 Interim Report (3), it was stated that many of the chlorinated organics on the WQB's Working List of Chemicals in the Great Lakes Basin, "because of their persistence, many will ultimately appear on the list of chemicals to be sunset." Because these substances are produced in diverse industrial processes, all of which involve the use of chlorine or its secondary products, the Task Force thus recommended all uses of chlorine be investigated.

The Commission's Science Advisory Board (SAB) came to similar conclusions in its 1989 and 1991 reports (4,5). The SAB found that the weight of evidence indicates that persistent toxic substances, particularly halogenated organics, are a hazard to human health and ecosystem integrity in the Great Lakes. The SAB found that the class of chlorinated organics tends to exhibit persistence and toxicity, and that evaluating and regulating these substances on a chemical-by-chemical basis is impractical and unscientific. The SAB thus concluded that organochlorines should be treated as a class and should be subject to phaseout, except in individual cases in which the weight of evidence supports the view that a chemical does not threaten health and the integrity of ecosystems.

Based upon these recommendations and its own deliberations, the Commission found, in its Sixth Biennial Report (2), that

"it is prudent, sensible, and necessary to treat these substances as a class rather than as a series of isolated individual chemicals."

Because chlorine is the common precursor in the diverse set of industrial processes that produce this class of substances, the Commission concluded that

"the use of chlorine and its compounds should be avoided in the manufacturing process."
Specifically, the Commission recommended that

"the Parties, in consultation with industry and other affected interests, develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and that the means of reducing or eliminating other uses be examined."

The Commission recognized that such a recommendation involves many industrial processes (and some non-industrial ones, as well) and that the socio-economic consequences of a phaseout program must be considered in determining the timetable. The purpose of this report to the Task Force is to propose elements of a framework for implementing a chlorine sunset program that is practical and consistent with the Commission's recommendation and findings.

FRAMEWORK FOR VIRTUAL ELIMINATION

A virtual elimination framework must be based on the following elements:

- The tactic of zero discharge from human activities.
- An integrated multi-media approach.
- Consideration of the full life cycle of products and processes.
- The weight of evidence.
- The reverse onus approach.

Each of these elements is already well established by the Agreement and the Commission, its boards or its task forces as necessary and appropriate policy responses to the problem of persistent toxic substances in the Great Lakes. This framework, however, represents a significant departure from the regulatory policies currently used by the Parties.

ZERO DISCHARGE means the elimination of all inputs of persistent toxic substances into the environment from human activities. This approach is based on the understanding that "acceptable" discharges of persistent toxic substances into an ecosystem will eventually build up to levels that will cause harmful effects. Zero discharge also means that it is not acceptable to transfer discharges of toxic substances from one medium to another (i.e. from air emissions to water discharges), using pollution control devices or other methods. Thus zero discharge implies an integrated multi-media approach.

Ultimately, zero discharge means sunsetting the products and processes that lead to persistent pollution. As the Task Force wrote in its 1991 report (3), "zero discharge does not mean less than detectable or best available technology or other means of treatment or control which, after application, continue to release some residual level." Because no existing methods of pollution control or disposal are absolutely effective, the only truly effective means of achieving zero discharge of persistent toxic chemicals is not to use or produce them in the first place.

The zero discharge approach must be applied to the full life cycle of products and processes. Many persistent toxic substances, for instance, occur as unintentional byproducts during the process of manufacture, use, or disposal of other products that are not themselves persistent toxic substances. Moreover, many chemicals are transformed in the environment into forms that are more persistent and/or toxic than the original. Thus, virtual elimination must not focus on the properties of individual chemicals in isolation; instead, it must consider the entire life cycle of chemicals and industrial processes, from the beginning of manufacture to transformation in the environment.

In its Sixth Biennial Report (2), the Commission recommended that the Parties adopt a weight-of-evidence approach to persistent toxic pollution. The effects of chemicals upon health and ecosystem integrity are extremely complex, and the tools currently available to toxicologists, epidemiologists, and other scientists are, with a few exceptions, unable to untangle the complex webs of cause and effect. Incontrovertible proof of causal links between individual chemicals and individual effects is not a reasonable standard, since the substances in the environment act together in complex mixtures to produce complex suites of effects.

REVERSE ONUS shifts the burden of proof, transforming a reactive policy into a precautionary approach. The current regulatory framework requires proof of harm before an industrial chemical is restricted. As the Science Advisory Board wrote in its 1989 report (4), this reactive approach is unscientific and dysfunctional, for a number of reasons. First, the vast majority of industrial chemicals in use have not been tested for adverse health effects, and new chemicals are being introduced at a rapid rate. Second, the introduction of man-made chemicals into natural systems is more likely than not to cause harm. Third, science proceeds not on the basis of proof but by establishing and disproving null hypotheses. The Board thus recommended that the burden of proof be shifted, so that those promoting the use of industrial chemicals must prove there is no reason to believe that those chemicals will threaten human and ecosystem health, before their use and discharge is permitted.

APPLICATION OF THE FRAMEWORK TO CHLORINATED ORGANICS

This case study of chlorinated organics illustrates how the above framework can be applied to a class of persistent toxic substances.

Under the current regulatory approach, the
Parties have instituted sunset programs for individual or small groups of chlorinated substances, including polychlorinated biphenyls (PCBs), chlorinated fluorocarbons (CFCs) and the pesticides DDT and dieldrin. These phaseouts have been largely effective at reducing inputs of the targeted substances into the environment. The inadequacy of the current framework is illustrated by the fact that these phaseouts have been adopted only after irrefutable evidence, gathered over the course of years or decades, has proven that the substance in question had already caused irreversible damage to human health and/or the environment. The current framework is also inadequate because contamination from these substances continues due to the amounts of them that were previously released, and because many chlorinated hydrocarbon pesticides that were banned or restricted for domestic use are still produced for export in large quantities.

The virtual elimination framework departs from this reactive, chemical-by-chemical approach, substituting a precautionary, pro-active policy that reverses the onus of proof for organochlorines as a class, for the reasons detailed below.

Zero Discharge and the Multi-media Approach

Zero discharge means that there can be no “acceptable” discharges of persistent toxic substances into the environment, and a multi-media approach is necessary to ensure that pollution control approaches do not merely shift discharges from one environmental medium to another. Under these two principles, processes and products that create persistent toxic substances must be phased out, not merely controlled or reduced.

The use of chlorine and chlorine compounds in the pulp and paper industry provides a useful example. The use of these chemicals as bleaching agents inevitably produces a spectrum of hundreds of chlorinated organic byproducts, many of which have been shown to be persistent and toxic, and many more of which are yet to be identified or investigated. Existing or proposed regulations have sought to require that effluent discharges of a few individual compounds, such as 2,3,7,8-TCDD (dioxin), or of total organochlorine discharges (measured, for instance, as AOX) be brought to some specified “acceptable” level through improved effluent treatment systems and reductions in the use of chlorine.

A zero discharge standard must apply to the release of chlorinated organics in wastewater discharges, air emissions, sludges, and the products themselves. Because the use of chlorine and chlorine-based bleaches gives rise to a multiplicity of identified and unidentified substances that are persistent and toxic (or the breakdown products of which are or may be persistent and toxic), the use of these chemicals as feedstocks must be eliminated.

Attention must be focused on the process that produces persistent toxic substances (the bleaching stage), not on measuring and controlling discharges after the substances have been formed.

The Life Cycle Approach

A life cycle approach does not merely focus on the properties of an individual product, as most phaseouts to date have; it also considers the formation of persistent toxic substances as byproducts, breakdown products, or transformation products during the manufacture, use, and disposal of a product and its wastes.

In the case of chlorinated organics, it is especially important to consider the entire life cycle, because many of the most persistent and toxic organochlorines are not manufactured intentionally at all, occurring instead as byproducts in many different chlorine-based processes. Because chlorine is highly unstable, it tends to react quickly with organic matter, producing a broad spectrum of hundreds or thousands of byproducts. Thus, organochlorines are not produced singly but in complex mixtures, and this phenomenon takes place throughout the life cycle of chlorine and its products: complex byproducts are generated when chlorine is produced through brine electrolysis, when chlorine is used in bleaching, disinfection, and metallurgical uses, whenever organochlorines are manufactured, and when chlorine-containing products are disposed by burning.

Because chlorinated organics are formed as mixtures, not singular chemicals, a sunset approach that evaluates and targets individual products based on their chemical characteristics is not adequate. Rather, the focus should be on processes and industrial sectors, which should be evaluated based on the generation of persistent toxics throughout their life cycle. Because the available evidence indicates that chlorine-based processes produce a spectrum of persistent toxic substances, it is sensible to target these processes (and the pollutants that result) as a class.

For instance, three of the 11 Critical Pollutants targeted for immediate sunsets are produced as byproducts in many chlorine-based processes (2,3,7,8-TCDD (dioxin), 2,3,7,8-TCDF (furan), and hexachlorobenzene. 2,3,7,8-TCDD and 2,3,7,8-TCDF, in fact, are never produced intentionally, but appear to be formed as byproducts of the chlorine industrial cycle and as products of incomplete combustion during incineration (37,46,66,78,85). The formation of these byproducts throughout the life cycle of chlorine is not surprising from a chemical or thermodynamic perspective, given the reactivity of chlorine and the stability of these byproducts once they are formed.

Because of their great persistence, toxicity, and ubiquity, the Commission recommended in its Sixth Biennial Report (2) that “the Parties, in consultation
with industry and other affected interests, alter production processes and feedstock chemicals so that dioxin, furan and hexachlorobenzene no longer result as byproducts."

But sunsetting substances that occur as byproducts does not mean banning the individual chemicals; rather, it means phasing out the many processes that generate them unintentionally. Virtual elimination of these byproducts requires the phaseout of many industrial uses of chlorine.

**The Weight-of-Evidence Approach**

A weight-of-evidence approach involves evaluating available information from multiple disciplines, recognizing data gaps, and using a precautionary approach that does not require absolute proof of cause-effect linkages before action is taken.

The weight of evidence shows that organochlorines — as a class — threaten the Great Lakes ecosystem (42-44,103; see also Appendix D). Over 150 organochlorines have been identified in the Great Lakes ecosystem and are considered pollutants of concern, according the WQB's working list (1). It has been estimated that there are thousands of organochlorine products in commerce, plus thousands more produced as unintentional byproducts. The majority of the compounds emitted from pulp mills and incinerators remain unidentified. In addition, identified compounds make up only a small fraction of the organochlorines and other pollutants present in biological samples (human and wildlife tissues) in the Great Lakes and elsewhere (6,7,9,66).

It would take generations to gather adequate data on the identity, sources, environmental behavior and effects of these hundreds or thousands of compounds to develop chemical-by-chemical regulations. Such an approach is not practical. Further, because the Commission has found that persistent toxic substances in the Great Lakes already pose a hazard to health and the environment, a program that would require decades of data-gathering before implementation must be rejected.

Moreover, organochlorines do not exert their effects in the environment on a chemical-by-chemical basis. Chlorinated organics are often transformed into a spectrum of breakdown products, many of which are more persistent or more toxic than the original compounds. Above all, organochlorines cause their effects in complex mixtures that add to or multiply the effects of individual compounds. If we wait for proof of harm on a chemical-by-chemical basis, we will not act in time to prevent further unacceptable damage to the health of the ecosystem, its wildlife, and its human residents.

The virtual elimination framework thus requires approaching chlorinated organics as a class. The weight of evidence shows that members of this class of compounds tend to be persistent toxic substances or to be associated with such substances during their life cycle. While each compound has its own chemical and biological properties, organochlorines tend to be persistent in some media and toxic; in fact, no other class of industrial or natural chemicals is known that exhibits so many detrimental properties.

The chemistry of chlorinated organic substances supports this weight of evidence. In fact, the characteristics that make chlorine and organochlorines useful in industrial applications are the same ones that make them problematic from an environmental perspective. For example (8):

- **Reactivity.** Chlorine's utility in bleaching, disinfection and chemical manufacture arises from its reactivity. For the same reason, however, byproducts are produced in all chlorine-based processes (9,66,85,100).

- **Persistence.** The addition of chlorine to a hydrocarbon "backbone" forms a more or less "impenetrable screen" that shields the molecule from chemical, physical, and biological breakdown. The more halogen atoms on a hydrocarbon, the longer it will remain intact (9). Thus, chlorinated organics are attractive for use as pesticides, plastics, solvents, and dielectric fluids. For the same reason, they tend to be highly persistent once released to the environment (46,74,78,85).

- **Chlorinated organics also tend to be resistant to fire, making them excellent flame retardants and extinguishers but nearly impossible to incinerate without producing significant quantities of toxic "products of incomplete combustion", or PCls (37,46,78,85).

- **Fat solubility.** Many chlorinated organics are far more soluble in fats than in water, and adding chlorine to a hydrocarbon backbone tends to increase a compound's lipophilicity. These substances thus find wide application as solvents, degreasers, etc. This same property, however, makes them subject to accumulation in the food chain, where they build up in increasing concentrations in fatty tissue, mother's milk, reproductive organs, and nerve membranes with their very high fat content.

- **Toxicity.** Organochlorines are useful as pesticides and antibiotics precisely because they are toxic (42-92; see also Appendix D). Once released into the environment, however, this toxicity will affect all exposed organisms, not simply the target "pest." Adding chlorine atoms onto a carbon skeleton increases lipid solubility, and increases toxicity on a molar basis (9,11,12).

The weight of evidence is strengthened by the fact that organochlorines are largely noxious or poisonous...
Appendix B

Many organochlorines are known to be produced naturally, mostly by fungi and algae, but these are usually produced in relatively small quantities and detected in or adjacent to the cells that produce them (45,101). The only organochlorine produced naturally in large quantities (reportedly 5 million tons per year) is the simplest organochlorine, the relatively non-persistent chloromethane, which is thought to play a role in the natural regulation of the ozone layer (13). This can be compared with United States production of chlorinated hydrocarbons in 1986 of almost 13 million tons (41).

Most importantly, virtually all natural organochlorines are produced precisely for their toxicity; they are used by the organisms that produce them as chemical defenses, antibiotics, natural pesticides, etc. (14,37). This fact further supports the inherent toxicity of this class of compounds and the need for human restraint in their industrial production.

For all these reasons, the weight of evidence supports the conclusion that organochlorines as a class tend to be associated with persistence and toxicity. This evidence suggests that organochlorines that have not yet been evaluated are more likely than not to turn out to share these characteristics.

The Reverse Onus Approach

Accordingly, the class of organochlorines should be subject to reverse onus -- the presumption that these compounds should be phased out unless evidence is presented to demonstrate that individual compounds or processes do not produce persistent toxic substances.

A virtual elimination program would thus begin with the presumption that processes that produce chlorinated organics -- the use of elemental chlorine and the production, use, and disposal of organochlorines -- should be phased out. The onus would shift to industry or other advocates to show that a given product or process does not result in the generation of persistent toxic substances during its life cycle. After such a determination, a product or process could be removed from the phaseout list.

ELEMENTS OF A SUNSET STRATEGY FOR CHLORINE

The virtual elimination framework thus requires "reversing the onus" for chlorinated organics and phasing out the chlorine-based processes that produce these substances. Implementing such a sunset program is a complex task, since so many products and processes are involved.

The sunset program should begin with a process of strategic prioritization to identify those sectors responsible for the largest discharges of persistent toxic substances in which a sunset program can be most effectively implemented. The following information is required:

- A systematic and comprehensive identification of those activities that constitute "chlorine chemistry" (the set of industrial and other activities that produce, use, and generate organochlorines).
- A chlorine use tree.
- A process/use life cycle matrix.
- Additional criteria of a social and economic nature.

With this information, the following questions should be answered:

- Which products or processes, throughout their life cycles, are most significant in contributing to releases of persistent toxic substances?
- What are the available alternatives for each sector? What are the environmental, health, safety characteristics of the alternatives? What are the socio-economic implications of implementing them?
- If no alternatives are currently available, how difficult is the alternative to develop?

This information can then be used to prioritize which sectors should be sunset first, to set timelines for phaseout, and to implement measures to accomplish the phaseout.

The sunset program can be implemented with a series of "sunset permits" for each process that produces or uses chlorinated organics, including a sunset date after which the permit expires and the process is no longer allowed. The permit would include a timetable for implementing necessary process changes and may include interim limits on the quantity of chlorine or organochlorines that may be used or produced. It is not necessary that such permits require the use of a specific alternative process -- merely that they eliminate the use of processes that generate persistent toxic substances and implement new ones that do not do so. When alternatives are not currently available, research programs should target the development of chlorine-free, environmentally sound processes.

OVERVIEW OF INDUSTRIAL USES OF CHLORINE

For the purpose of the use tree and life cycle matrix that follows, industrial uses of chlorine include the following activities:

1. Production of chlorine (along with hydrogen and sodium hydroxide) in chlor-alkali electrolysis.
2. Uses of elemental chlorine, e.g.:
   - pulp and paper
   - inorganic chemical production
   - water and wastewater treatment
   - certain metallurgical processes

3. Production of chlorine-containing bulk products, e.g.:
   - Polyvinyl chloride (PVC)/vinyl chloride (VC)/ethylene dichloride
   - Chlorinated solvents and other chlorinated methanes, ethanes and ethylenes
   - Chlorinated fluorocarbons (CFCs) and HCFCs
   - Neoprene (polychlorobutadiene)

4. Production and use of chlorinated feedstocks for specialty products, e.g.:
   - Chlorinated benzenes, nitrobenzenes, and other aromatics (for pesticides, dyes, plasticizers, etc.)
   - Chloroacetic acid (for pesticides and other uses)
   - Cyanuric chloride (for pesticides and other uses)

5. Use of chlorinated pesticides and other specialty products.

6. Production of chlorinated intermediates for chlorine-free bulk products:
   - propylene chlorohydrin for propylene oxide (for polyurethane, brake fluids, anti-freezes, etc.)
   - epichlorohydrin (for epoxy resins and other uses)
   - phosgene (for isocyanates for polyurethane and other uses)
   - methyl chloride (for methyl cellulose, silicones, etc.)

7. Production of chlorine-containing auxiliary products/additives:
   - plasticizers (in plastics)
   - flame retardants (in plastics)
   - scavengers (in fuels)
   - stabilizers (in lubricating and cutting oils)
   - PCBs

8. Production of inorganic compounds, e.g.:
   - bleaches
   - detergents
   - cleaners and powders
   - metallic chlorides

9. Disposal or reprocessing of chlorinated wastes, e.g.:
   - municipal waste incinerators
   - hazardous waste incinerators
   - hospital waste incinerators
   - metals recovery activities that burn electric, electronic, and cable scrap containing PVC and other chlorinated organics
   - other disposal or reprocessing facilities

Appendix B

THE CHLORINE USE TREE

This list initially appears highly complex, involving thousands of substances, dozens of industrial processes, and thousands of individual users. Attempting to regulate effectively at this level of complexity is impractical, and would lead to regulatory gridlock.

Clearly, another approach is necessary. A use tree allows us to view chlorine-based substances and processes more holistically. The tree organizes the many chlorine-based processes into a series of activities from the most basic to the more specialized. The initial processes begin with the trunk and its roots; as processes and substances become more specialized, they are represented as limbs, branches, and finally twigs. The chlorine use tree begins at the root -- the production of chlorine -- and then traces the various processes and products in which chlorine and its secondary products are used and finally disposed.

Figure B-2 is a chlorine use tree with a high degree of detail on substances and process branchings (15). Figure B-3 presents a simpler use tree that identifies major bulk products, processes, and application categories. This simpler use tree is still detailed enough to work with for purposes of choosing points of intervention based upon major problem categories of products, processes, and applications relatively early in their life cycle.

Generally, the farther out in the tree one goes, the later it is in the life cycle, the greater the specialized branchings and multiplicity of possible release points, the greater the problem complexity and transaction costs, and the less likely that intervention or remedial action will be practical, feasible, or effective. It is obviously much easier to intervene, and "prune" the use tree of undesirable processes and products at the points where they emanate from the roots and trunk to the 5 to 10 or so main branches, representing the bulk products and processes, than to allow the multiple specialty product/application branchings to proliferate into the hundreds and thousands, and then try to work at that level.

The use tree allows full life cycle evaluations of products and processes. It is particularly important to trace products that contain substantial quantities of persistent toxic substances or their precursors, that are not released immediately, but sometime later in their life cycle. Table B-2 is an example of a process/use life cycle matrix that considers the industrial and environmental transformations for important aspects of chlorine chemistry.

THE CHLORINE USE TREE ANALYSIS

Production and Use

Tables B-3 and B-4 show data on recent trends and levels of chlorine production and major bulk user
Appendix B
Chlorine and Hydrochloric Acid Derivatives

**Chlorine**
- Electrolysis of brine
- Electrolysis of fused salt
- Electrolysis of magnesium chloride
- Electrolysis of hydrochloric acid
- Catalytic oxidation of hydrochloric acid
- Chemical reaction of potassium chloride and nitric acid

**Production of Organic Chemicals**
- By oxychlorination processes (often interchangeable with oxyhydrochlorination processes)
- By production of organic chemicals

**Production of Inorganic Chemicals**
- Sanitizing and disinfecting agent (e.g. for municipal water supplies, swimming pools)
- Waste and sewage treatment

**Slimize**
- Bleach
- Textiles

**Sodium Chlorate**
- Hypochlorous acid
- Chlorinated isocyanurates (potassium dichloroisocyanurate, sodium dichloroisocyanurate, trichloroisocyanuric acid)
- Hydrochloric acid
- Phosphorus trichloride
- Phosphorus pentachloride
- Phosphorus oxychloride
- Titanium trichloride
- Titanium tetrachloride
- Ferric chloride (by-product of titanium tetrachloride production)
- Aluminum chloride, anhydrous
- Sulfur monochloride
- Sulfur dichloride
- Sulfuryl chloride
- Mercurous chloride
- Mercuric chloride
- Silicon tetrachloride
- Zinc chloride from zinc metal
- Antimony pentachloride
- Antimony trichloride
- Stannous chloride
- Arsenic trichloride
- Bismuth trichloride
- Chlorine trifluoride
- Molybdenum pentachloride
- Iodine monochloride
- Iodine trichloride

**Chlorinated Paraffins**
- High pressure lubricants
- Fireproofing agent for textiles (with antimony oxide)
- Plasticizer for poly(vinyl chloride) detergents

**Chlorinated Waxes**
- Moisture-, flame-, acid-, and insect-proofing of wood, fabrics, wire, and cable solvent

**Herbicides**
- Chlorosacetyl chloride
- Dichlorobenzene
- Dichlorobenzenes
- Trichlorobenzene
- Tetrachlorobenzene
- Benzene hexachloride
- Polychlorinated biphenyls
- Chlorotoluenes
- Hexachlorobutane
- Chlorophenols
- Chloral
- Hexachlorocyclopentadiene
- Perchlordimethyl
- Mercaptan
- Tetrachlorophthalic anhydride

**Sanitizers**
- Textiles
- Wood pulp
- Organic synthesis
- Dye intermediate
- Fumigant
- Flame retardant for plastics

**Pharmaceuticals**
- Pharmaceutical (antiseptic)
- Pharmaceutical (anti-septic)

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Appendix B

Figure B-2, continued
Chlorine and Hydrochloric Acid Derivatives

- Ferric chloride (by-product)
  - Steel pickling

- Production of chlorinated hydrocarbons via oxyhydrochlorination processes (often interchangeable with oxychlorination processes)
  - Vinyl chloride from acetylene ethyl chloride other chlorinated hydrocarbons

- Methyl chloride ethyl chloride 1,4-dichlorobutane (tetrachloroethylene dichloride) higher alkyl chlorides
  - Adiponitrile other organic synthesis products

- Organometallics alkylchlorosilanes
  - Silicone resins and elastomers

- Hydrochloric acid
  - By-product from salt and sulfuric acid from chlorine and hydrogen
  - Chemical milling baths (metal working)
  - Gaseous flux for babbitting operation
  - Chemical reagent and intermediate oil well acidizing food processing (e.g. in sugar refining, brewing industry, and for manufacture of monosodium glutamate and gelatin)
  - Catalyst for production of aniline by nitrobenzene reduction latex coagulating agent deliming agent for hides
  - Desulfurization agent for petroleum pH control scale removal veterinary medicine

- Production of hydrochlorides
  - Aniline hydrochloride diphenylamine dyes
  - Amine hydrochlorides
  - Hydrazine dihydrochloride other hydrochlorides

- Production of alkyl chlorides via substitution reactions
  - Production of metallic chlorides and other inorganic chemicals
  - Zirconium water repellent agent pigments

- Zirconium tetrachloride
  - Refractories alloys photoflash bulbs pyrotechnics

- Chlorine silica gel silica, hydrated other inorganic chemicals
  - Aniline hydrochloride rubber accelerator plastics stabilizer rocket propellants pesticides
  - Diphenylamine dyes
  - Amine hydrochlorides
  - Hydrazine dihydrochloride
  - Other hydrochlorides

- Desulfurization agent for petroleum pH control scale removal veterinary medicine

- Modifier in ore beneficiation (flotation) processes refining of tin and tantalum

- Calcium chloride (waste by-product)
  - Aluminum chloride, anhydrous barium chloride cadmium chloride cobaltous chloride cupric chloride magnesium chloride from brines nickel chloride stannic chloride titanium tetrachloride chlorosulfonic acid

- Zinc chloride antimony trichloride arsenic trioxide bismuth trichloride lithium chloride zirconium tetrachloride

- Chlorine scavenger for hydrogen chloride gas streams
Appendix B

Figure B-3

Chlorinated Organic Chemicals

- Bulk & Raw Products
  - Chlorolysis
  - Additives
  - Chlorine-Free Bulk Products

Chlorinated Organic Chemicals

- Bleaching Processes
- Inorganic Chemicals
- Water & Sewage Treatment
  - Refining
  - Milling
  - Reagents
  - Food Processing

Chlorine

Polyvinyl Chloride
- Solvents - especially ethanes & ethylenes
- Pest & weed control (e.g. 2,4-D, 2,4,5-T)
- Reprocess waste & used chlor-products (Per-, Tri-, Carbon tetra-)

Plasticizers
- Flame retardants
- Moisture proofing
- Scavengers (fuels)
- Stabilizers (oils)
- Hydraulic fluids, Insulators (PCBs)

Polyurethane
- Propylene Glycol
- Epoxy Resins (i.e. propenes, pentanes)

Paper Products
- Textiles

Household Bleaches
- Detergents
- Cleaners & powders

Disinfectants & sanitizing agents

Vinyl Chloride (i.e. chloro-hydrocarbons)

Methyl Chloride (i.e. alkyl-chlorides)

Alloying processes (i.e. metallic chlorides)

Stabilizers (plastics)
- Accelerators (rubber)
- Scavengers (flue gas)
- Propellants & refrigerants (CFCs) (i.e. halogenated substances)
groups (16). North American chlorine production now totals about 13 million tons per year.

By far, the largest single use of chlorine in both the U.S. and Canada is the production of polyvinyl chloride (PVC) plastic. Second in each country is the use of chlorine as a bleaching agent in the paper industry, followed by the production of chlorinated solvents and precursors for polyurethane. Disinfection of wastewater and drinking water account for about 5% of total chlorine use, with drinking water a relatively small portion of that amount. By comparison, all other specialty uses are relatively minor.

The major trends include the following:

- Increases in total chlorine production between 1985 and 1988, due mainly to increased consumption in pulp and paper demand, and increases in the production of PVC and its precursors ethylene dichloride (EDC) and vinyl chloride (VC).
- Recent declines in the use of chlorine in pulp and paper since 1988.
- Reductions in production of chlorinated solvents, due to phaseouts of CFCs and replacement of chlorinated solvents in manufacturing industries with process changes or non-chemical methods of cleaning, coating, and extraction.
- Substantial recent and projected growth in PVC production—the only major sector expected to expand. U.S. exports of PVC precursors are also on the increase.

### Table B-2

Process/Use Matrix of Persistent Toxic Substances in the Great Lakes (Mercury and Chlorine)

<table>
<thead>
<tr>
<th>Life Cycle Stage</th>
<th>Utilities &amp; Smelters</th>
<th>Manufacturing Activity &amp; Product Use</th>
<th>Municipal &amp; Industrial Waste Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production Process</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Input</td>
<td>Utility cost (Hg)</td>
<td>Chloralkali electrolysis (Cl &amp; Hg)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kraft paper &amp; textile bleaching processes (Cl)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polyvinyl chlorides (PVCs); propylene &amp; epoxys</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solvents (esp. ethanes &amp; ethylenes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chlorolysis (per-, tri, carbon tetrachloride)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chlorinated methanes (CCl₄, CHCl₃)</td>
<td></td>
</tr>
<tr>
<td>- Output</td>
<td></td>
<td>Pulp wastes - adsorbable organic halide (AOX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary treatment lagoons (AOX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial fuel combustion (Hg &amp; PCBs)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incineration of sludge (AOX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pulping processes - dioxins &amp; furans</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2,3,7,8-TCDD &amp; 2,3,7,8-TCDF)</td>
<td></td>
</tr>
<tr>
<td><strong>Direct Discharge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Effluents</td>
<td>Thermal power generation (Hg &amp; PCBs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonferrous metal production (Hg, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Emissions</td>
<td></td>
<td>Pulp wastes - adsorbable organic halide (AOX)</td>
<td>Copper, lead, &amp; zinc slag (Hg, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Secondary treatment lagoons (AOX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial fuel combustion (Hg &amp; PCBs)</td>
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<td></td>
<td></td>
<td>Incineration of sludge (AOX)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Pulping processes - dioxins &amp; furans</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2,3,7,8-TCDD &amp; 2,3,7,8-TCDF)</td>
<td></td>
</tr>
<tr>
<td>- Solids</td>
<td></td>
<td>Open manufacturing &amp; thermal processes (Hg, pyrolysis)</td>
<td>Landfills &amp; building sites (e.g. pumps, transformers, used oil &amp; parts, materials)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical generators &amp; transformers, hydraulic fluids &amp; lubricants (spills &amp; volatilization of PCBs)</td>
<td>Incinerators (misc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chlorinated solvents, pesticides, phenols &amp; benzenes (HCBs, PCBs, TCDDs &amp; TCDFs)</td>
<td>Water purification (Cl)</td>
</tr>
<tr>
<td></td>
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<tr>
<td><strong>Indirect Release</strong></td>
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</tr>
<tr>
<td>- Spills &amp; dumping</td>
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<td></td>
</tr>
<tr>
<td>- Incineration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Leachate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Sediments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>End Uses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Products</td>
<td></td>
<td>Aerosols &amp; refrigerants (CFCs)</td>
<td>Batteries &amp; paint (e.g. Hg, Pb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herbicides (e.g. chlorophenoxy, 2,4-D, 2,4,5-T), fungicides (e.g. HCBs) &amp; chlorinated organic pesticides</td>
<td>Scrap metal (e.g. electronic parts, autos, electric cable &amp; wire)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plastics, textiles &amp; fuels (use of halogenated additives)</td>
<td>Plastics &amp; packaging (e.g. PVC)</td>
</tr>
<tr>
<td><strong>Disposal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Mechanical &amp; source separation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Containment/ recovery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Reduce/recycle/ reuse</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Table B-3
#### Canadian Demand Pattern

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kilotonne (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene dichloride</td>
<td>594.0 (39.0)</td>
<td>645.0 (36.6)</td>
<td>675.0 (41.1)</td>
<td>NA</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>430.0 (28.0)</td>
<td>505.0 (28.6)</td>
<td>420.0 (25.5)</td>
<td>NA</td>
</tr>
<tr>
<td>Mining and smelting</td>
<td>7.0 (0.5)</td>
<td>8.0 (0.5)</td>
<td>7.0 (0.4)</td>
<td>NA</td>
</tr>
<tr>
<td>Water treatment</td>
<td>18.0 (1.2)</td>
<td>19.0 (1.1)</td>
<td>18.5 (1.1)</td>
<td>NA</td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>32.5 (2.1)</td>
<td>32.0 (1.8)</td>
<td>30.0 (1.8)</td>
<td>NA</td>
</tr>
<tr>
<td>Aluminum chloride</td>
<td>11.5 (0.8)</td>
<td>12.0 (0.7)</td>
<td>14.0 (0.9)</td>
<td>NA</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>12.0 (0.8)</td>
<td>13.0 (0.7)</td>
<td>13.5 (0.8)</td>
<td>NA</td>
</tr>
<tr>
<td>Chlorinated solvents</td>
<td>71.0 (4.7)</td>
<td>74.0 (4.2)</td>
<td>70.0 (4.3)</td>
<td>NA</td>
</tr>
<tr>
<td>Propylene oxide</td>
<td>82.0 (5.4)</td>
<td>82.0 (4.7)</td>
<td>850.0 (5.2)</td>
<td>NA</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5.4 (0.4)</td>
<td>9.7 (0.6)</td>
<td>9.0 (0.6)</td>
<td>NA</td>
</tr>
<tr>
<td>Total Canadian Demand</td>
<td>1,263.4</td>
<td>1,399.7</td>
<td>1,342.0</td>
<td></td>
</tr>
<tr>
<td>Exports</td>
<td>257.6 (17.0)</td>
<td>363.4 (20.8)</td>
<td>322.5 (19.6)</td>
<td>NA</td>
</tr>
<tr>
<td>Total disappearance</td>
<td>1,521.0</td>
<td>1,763.1</td>
<td>1,644.5</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Other inorganics includes titanium dioxide, and other organics includes epichlorohydrin. United States exports in 1992 are ethylene dichloride.

*Source: Reference (16). 1992 data adapted from (27).*

### Table B-4
#### United States Demand Pattern

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Kilotonne (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene dichloride</td>
<td>2,037.0 (21.0)</td>
<td>2,590.0 (24.4)</td>
<td>2,820.0 (26.6)</td>
<td>30</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>1,554.0 (16.0)</td>
<td>1,740.0 (16.4)</td>
<td>1,470.0 (13.8)</td>
<td>11</td>
</tr>
<tr>
<td>Inorganic chemicals</td>
<td>1,165.0 (12.0)</td>
<td>1,172.0 (11.1)</td>
<td>1,210.0 (11.4)</td>
<td>11</td>
</tr>
<tr>
<td>Chlorinated methanes</td>
<td>778.3 (8.0)</td>
<td>790.4 (7.5)</td>
<td>780.0 (7.3)</td>
<td>5</td>
</tr>
<tr>
<td>Chlorinated ethanes</td>
<td>918.3 (9.5)</td>
<td>864.7 (8.2)</td>
<td>850.0 (8.0)</td>
<td>5</td>
</tr>
<tr>
<td>Water treatment</td>
<td>425.3 (4.4)</td>
<td>527.2 (5.0)</td>
<td>540.0 (5.1)</td>
<td>5</td>
</tr>
<tr>
<td>Propylene oxide</td>
<td>628.3 (6.5)</td>
<td>685.4 (6.5)</td>
<td>706.0 (6.7)</td>
<td>8</td>
</tr>
<tr>
<td>Other organics</td>
<td>1,705.6 (17.6)</td>
<td>1,715.3 (16.2)</td>
<td>1,750.0 (16.5)</td>
<td>16</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>454.9 (4.7)</td>
<td>459.8 (4.3)</td>
<td>450.0 (4.2)</td>
<td>4</td>
</tr>
<tr>
<td>Total United States Demand</td>
<td>9,666.7</td>
<td>10,544.8</td>
<td>10,576.0</td>
<td></td>
</tr>
<tr>
<td>Exports</td>
<td>51.3 (0.5)</td>
<td>58.2 (0.6)</td>
<td>44.0 (0.4)</td>
<td>5</td>
</tr>
<tr>
<td>Total disappearance</td>
<td>9,718.0</td>
<td>10,603.0</td>
<td>10,620.0</td>
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</tr>
</tbody>
</table>

*Note: Other inorganics includes titanium dioxide, and other organics includes epichlorohydrin. United States exports in 1992 are ethylene dichloride.

*Source: Reference (16). 1992 data adapted from (27).*
Chlorine and Caustic Soda Production: The Root

Virtually all chlorine in North America is produced by the chlor-alkali process, in which brine (salt water) is subjected to an intense electric current to produce chlorine and the coproducts sodium hydroxide (also called caustic soda) and hydrogen. This process is the root of the chlorine chemistry tree: the chlorine produced here is the basic feedstock in the production of all other organochlorine products and byproducts.

The coupling of chlorine and caustic soda production has important implications for the phaseout of chlorine. Caustic soda, which itself is not known to be associated with the production of persistent toxic substances, is used in diverse industrial activities, including the manufacture of aluminum, glass, chemicals, and textiles, as well as in water treatment and petroleum refining.

Indeed, a main stimulus to the early development of chlorine chemistry was the need to make use of the chlorine surpluses from sodium hydroxide production. Today, chlor-alkali producers continue to make virtually all their profits from alkali, not from chlorine. Because alkali demand continues to increase, and because chlorine is difficult to store, producers need a “sink” for chlorine -- other industrial processes and products, such as PVC and pulp and paper. Thus, production of at least some persistent chlorinated organics is currently driven by demand for caustic soda.

Chlorine producers are counting on PVC growth to offset decreases in other major sectors as PVC becomes the “sink” into which chlor-alkali producers dump excess chlorine in order to keep pace with growing demand for caustic soda (17-22).

Sunsetting chlorine could result in a sharply curtailed supply of sodium hydroxide. This issue can be resolved in a number of ways. First, caustic soda consumption can be reduced significantly through conservation and recycling. Second, caustic soda consumption can be reduced through the use of alternative alkalis or sodium sources. Finally, caustic soda can be produced through methods other than the chlor-alkali process. The production of chlorine and caustic soda can thus be uncoupled.

Caustic is produced raw in three main ways: by the chlor-alkali process; by recastigising sodium carbonate using lime by the old Solvay process; and by causticization of sodium carbonate mined as trona ore (a natural mineral that is mostly sodium carbonate). There are reports of shifts to these latter two processes, with the Solvay method leading (18).

There are trona deposits in a number of locations around the world. The largest deposit by far is in Wyoming (23). Several companies are currently exploiting these resources for soda ash and/or caustic, including the Solvay company, which is a large chlor-alkali producer. Other large companies are reportedly looking into the possibility (24). The potential for further development of this process is just beginning to be tapped, and estimated trona reserves are enough to supply world caustic demand for several hundred years (23).

Caustic soda can also be produced from electrolysis or electrodialysis of sodium sulfate, and this process is already in use at pilot facilities. Sodium sulfate is an abundant natural mineral and is also present in the wastewater streams of a number of industries, for example, pulp mills, rayon production, and chemical plants (25). According to U.S. Environmental Protection Agency’s (EPA) Toxic Release Inventory, industry discharged more than 4.5 million tons of sodium sulfate to surface waters in 1987, some of which could presumably be recovered for reuse.

Measures to reduce caustic demand are also available. Efficiency and recycling programs can substantially reduce the need for caustic. The caustic loop in the pulp and paper industry can be almost closed if chlorine (and its corrosive byproducts) are eliminated from the bleaching process, reducing caustic demand by up to 80% in this sector. Opportunities for significant reduction (50% or more) are also reported in other sectors, such as aluminum oxide production and petroleum refining.

Other chemicals can often take the place of caustic soda, further reducing demand. Carbonates, lime and magnesium hydroxide can be used for many purposes requiring an alkaline environment (18). It is reported that Dow Chemical successfully substituted lime for 500,000 tons per year of caustic in the production of propylene oxide (26). If the need is for sodium ions, sodium carbonate or sulfate can often be substituted.

Together, conservation, substitution, and “chlorine-free caustic” should allow a substantial decrease in demand for caustic produced by the chlor-alkali process in the short term. In the long term, these methods appear adequate to substitute for chlor-alkali caustic entirely.

Moving up the Chlorine Use Tree

Since chlorine and caustic soda production can be decoupled, it is possible to contemplate a drastic reduction in chlorine production, and to freely analyze the main trunk and branches of the chlorine use tree. The majority of chlorine production (80 to more than 90%) is used in just 8 to 10 easily discernible product groups or applications. A much smaller amount (5 to 20%) finds its way into the specialty chemicals segments (excluding solvents) with more highly diversified product groups, and correspondingly complicated phaseout scenarios.
The relatively few major product groups are shown in Tables 8-3 and 8-4. In Canada, the use of chlorine is dominated by EDC (for production of VC/PVC) (41.1%), pulp and paper (25.5%), exports (which may be as EDC, as it is reported to be in the U.S.) (19.6%), propylene oxide (5.2%), and chlorinated solvents (4.3%). These uses account for 95.7% of the total (16).

In the U.S., chlorine use within the chemical industry is more specialized, leading to a more complex tree. Nevertheless, the bulk of total chlorine use still falls into relatively few groups. Use of chlorine in EDC-VC-PVC (35%, including exports), pulp and paper (14%), chlorinated methanes and ethanes (e.g. solvents, 10%), propylene oxide (8%) and water treatment (5%) account for 67% of total chlorine use. The remainder is in inorganic chemicals (11%), other organics (16%), and miscellaneous (4%) (16).

Even within the “specialty chemicals,” major products, such as chlorinated pesticides, tend to dominate and are thus relatively easy to classify. There are other major products and applications that are also easily discernible. The use tree branchings become complicated, rather than simple, only in those specialty uses associated with organic and inorganic chemical production (Figure B-2). Addressing the problem at this highly fragmented resolution will likely be ineffective as a regulatory approach.

Disposal activities in the life cycle (for example, waste incineration and scrap metals recovery) are also part of the chlorine chemistry family, and contribute substantially to the loading of persistent toxic substances into the environment. Because these activities are largely downstream of production and use, they will ultimately be reduced as chlorine use declines. However, these sectors require specific and immediate attention, as there is a large existing inventory and will be an ongoing supply of chlorinated materials that can become feedstock for these processes, resulting in continuing discharges of persistent toxic substances to the environment.

A detailed discussion of each major sector is beyond the scope of this report to the Task Force. However, a few major product and process groupings can illustrate the application of the strategy. For each, the relative significance as a source of persistent toxic substances will be considered, along with the availability of alternatives and the implications of their implementation.

ETHYLENE DICHLORIDE/VINYL CHLORIDE/ POLYVINYL CHLORIDE

Significance as a Source of Persistent Toxic Substances

Polyvinyl chloride (PVC) -- along with its precursors ethylene dichloride (EDC) and vinyl chloride (VC) -- is by far the largest single use of chlorine. It is also the only major use sector that is growing. As long as industry is wedded to the coupled production of chlorine and caustic, PVC is likely to remain the sink for the chlorine surplus due to declines in other uses.

Thus, the industry has sought to expand PVC markets in the last 10 to 15 years and has made significant inroads into uses in which traditional materials were formerly used, such as packaging, pipes, flooring, siding, and furniture. For future expansion, markets in developing countries are reportedly targeted for significant growth (22).

Some have suggested that PVC is not of environmental concern, because the products are relatively inert and non-toxic. A consideration of the full life cycle of PVC, however, indicates substantial releases of persistent toxic substances to the environment. The most significant releases take place during manufacture and disposal.

The basic feedstocks for PVC -- ethylene dichloride and vinyl chloride -- are both extremely toxic, with effects including cancer, birth defects, cardiovascular toxicity, and damage to the liver, kidneys and nervous system. Once released to the air, vinyl chloride is degraded into a number of other chlorinated organics and inorganics; in water, it is extremely persistent. EDC is also highly persistent in water and is far more persistent in the air, with a half-life estimated at four months (28).

Production facilities emit these feedstocks into air and water in large quantities, with self-reported air emissions of VC by U.S. industry totalling 1.3 million pounds per year, plus an additional 0.6 million pounds per year to off-site waste facilities (28). Worker exposures are also of significant concern, and excess rates of cancer (especially angiosarcoma) have been documented among vinyl chloride workers (28).

Manufacture of these feedstocks involves the generation of large quantities of waste (including light ends, heavy ends, and oxychlorination tars) that include a range of persistent toxic substances such as hexachlorobenzene and hexachlorobutadiene. Recently, very high concentrations of polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) have been discovered in the wastes from the production of ethylene dichloride by oxychlorination (17,29,30). If the concentrations of PCDD/Fs found in oxychlorination tars to date (in the hundreds of parts per billion) are representative of other plants, this process may be the largest single source of dioxin formation.

A large portion of these wastes are incinerated, leading to dispersal of some portion of the persistent toxic substances while also creating further quantities of persistent toxic substances as products of incomplete combustion. PCDD/Fs have also been documented in air emissions and water discharges from these processes; the majority of dioxins in sediments...
of the River Rhine in the Netherlands have been attributed to wastewater discharges from EDC-VC production processes. Some portion of the wastes are also redirected to onward use in the production of chlorinated solvents.

The pure PVC resulting from this production process is reported to be a poor quality plastic in pure form, and cannot be used without a range of additives (22,31). These additives include plasticizers, heat stabilizers, pigments, biocides, flame retardants, and others (31). Many of these additives are themselves persistent toxic substances: use as PVC additives account for significant proportions of total use of such ubiquitous substances as di-2-ethyl-hexyl phthalate and other phthalates, cadmium, lead, organo-tin compounds, and chlorinated paraffins. U.S. production of all plastics additives was 10,230 million pounds in 1991 (31). The additives escape to the environment through emissions and wastes in their production and in the production of PVC products, through leaching during the lifetime of PVC products, and in disposal of the products.

Large quantities of persistent toxic substances are released to the environment during the final stage of the life cycle of PVC -- disposal. Because of the complexity of PVC product mixes, recycling of PVC is, at present, not practical, because of the need to separate the various PVC mixes to ensure a quality product (22,29-31). However, it is reported that PVC insulation from wire and cable is recycled in significant quantities by a large recycler (Waxman) in Hamilton, Ontario, using mechanical separation. In landfills, additives may be leached, particularly in the presence of organic solvents. Plasticizers are of particular concern in this regard, as they do not form a stable chemical bond with the PVC.

When burned, the chlorine in PVC is transformed into hydrogen chloride and chlorinated products of incomplete combustion, including hexachlorobenzene, PCBs, and the PCDD/Fs. PVC is the largest single source of chlorine in incinerators for municipal waste and hospital waste. It is also the largest source of cadmium and a significant source of lead (22). Short-term PVC uses, such as packaging, are especially problematic from the point of view of the feed of chlorine into incinerators. However, at some point in the near future, the millions of tons of PVC now in medium- and long-term uses (siding, pipes, toys, etc.) will ultimately be turned over and become a waste disposal burden in the future.

The burning of PVC in house and building fires is also a significant source of persistent toxic substances. When PVC pipes, siding, flooring, furniture, and other materials burn in such fires, a full range of products of incomplete combustion are formed (including PCDDs and PCDFs); unburned phthalates, heavy metals, and other additives are released, as well. The health and safety threat to firefighters facing such "chemical fires" are well known. A report published in 1991 by the German EPA shows a link between dioxin formation and chlorinated plastics, especially PVC, in fire (32).

PVC can also be a major source of chlorine in metals recovery activities that burn used cables, electric and electronic scrap. These activities have been identified as major sources of PCDDs, PCDFs, and other persistent chlorinated substances.

PVC is thus associated with the formation and discharge of large amounts of persistent toxic substances to the environment throughout its life cycle. On this basis PVC is reputed to be the most environmentally unfriendly of all major plastics. Recent reports by the Tellus Institute and the German EPA have concluded that PVC causes greater environmental problems than chlorine-free plastics like polyethylene and polypropylene (33).

Availability of Alternatives

PVC uses in the U.S. are summarized in Table B-5.

Alternatives to PVC are specific to individual uses and include wood, linoleum, non-chlorinated plastics, metals, glass, paper/cardboard, etc. For instance, in piping (the largest single PVC use), pipes made of metal or chlorine-free plastics can completely substitute for PVC. As noted above, "traditional" materials have fulfilled most uses that are now PVC until very recently. Uses in which plastics are "necessary" (for example, cars and cable insulation), can be replaced with non-chlorinated plastics, such as ABS (acrylonitrile-butadiene-styrene), SAN (styrene-acrylonitrile), polyethylene, polypropylene, polyvinyl alcohols, polyamines, chlorine-free poly-carbonates, acrylics, and so on, depending on the properties needed.

A growing environmental awareness of PVC in Europe has led to successful efforts to phaseout PVC in a wide range of uses, including construction, commercial and medical packaging, automobiles, and furniture. Two years after adopting a policy to strive to eliminate PVC in public construction projects, the German town of Bielefeld has achieved 90% substitution of PVC in its construction activities. At least 80 other local authorities in Germany, plus two states and half the regional capitals in Austria, also have PVC phaseout policies in public construction. The recently reconstructed Vienna public transportation system is virtually PVC-free, and the automobile manufacturer Volkswagen has stopped using PVC in its products. Other manufacturers of appliances and electronic goods (AEG) and office supplies (Herlitz) have also eliminated PVC in their product lines. The Swedish furniture maker IKEA has announced a PVC phaseout policy. In packaging, a Danish supermarket chain has achieved 99% reduction of PVC in all its product lines, and PVC packaging has been phased
Table B-5
PVC Use Patterns in the United States

<table>
<thead>
<tr>
<th>PVC Use</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe and fittings</td>
<td>39</td>
</tr>
<tr>
<td>Siding</td>
<td>10</td>
</tr>
<tr>
<td>Wire and cables</td>
<td>4</td>
</tr>
<tr>
<td>Extruded profiles (i.e. window frames)</td>
<td>6</td>
</tr>
<tr>
<td>Roll goods</td>
<td>11</td>
</tr>
<tr>
<td>Coating and flooring</td>
<td>6</td>
</tr>
<tr>
<td>Packaging</td>
<td>5</td>
</tr>
<tr>
<td>Furniture</td>
<td>1.2</td>
</tr>
<tr>
<td>Appliances</td>
<td>1.8</td>
</tr>
<tr>
<td>Toys</td>
<td>0.4</td>
</tr>
<tr>
<td>Housewares</td>
<td>0.9</td>
</tr>
<tr>
<td>Exports</td>
<td>13</td>
</tr>
<tr>
<td>Others</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: References (22,34).

As demonstrated by European efforts, phaseout programs can successfully concentrate on major user-sectors of PVC, based on the relative importance of each sector and the availability of alternatives, achieving significant reductions in PVC consumption.

Implementing a phaseout will, of course, require action by the Parties. The following measures are available to a sunset program:

1. Sunset permits for the manufacturers of PVC.
2. Rapid phaseouts of PVC in uses that are quickly disposed (i.e. packaging).
3. Prohibition of the incineration of PVC in municipal and hospital waste incinerators.
4. Rapid phaseouts of PVC in uses that are susceptible to fire (i.e. construction and automobiles).
5. Require that mechanical separation of PVC from metal scrap is, and remains the only acceptable technology, or rapid phaseout of PVC in such uses.
6. Phaseout on specified timelines for other medium and long-term uses.
7. Other measures, including environmental taxes on PVC; product labeling and consumer education; government procurement of PVC-free products and PVC-free construction in public buildings; disposal surcharges on PVC products.

The socio-economic impacts of phasing out PVC are beyond the scope of this review. The European experience suggests that the alternatives are well within the range of affordability. Methods of addressing the impacts on workers currently employed in PVC production should be investigated along with phaseout programs (i.e. worker compensation, re-education and retraining; public investment in development of alternative economic activities; etc.).

PULP AND PAPER
Significance as a Source of Persistent Toxic Discharges

The use of chlorine and chlorine compounds in the pulp and paper industry is the second largest use of chlorine in the U.S. and Canada. These bleaching agents are used to remove residual lignins from wood pulp to make the resulting paper bright white.

Chlorine combines with this organic material to produce thousands of organochlorines, about 300 of which have been identified, including chlorinated aliphatics, acids, phenols, guaiacols, and dioxins (66). As much as 97% of the total organically-bound chlorine, however, is associated with unidentified medium- and high-molecular weight organics, which have been shown to break down into lower-weight chlorinated organics, many of which are persistent toxic substances (10,37,66,67). Organochlorines formed in the bleaching process are discharged to the environment via effluent discharges, air emissions of volatile compounds, disposal of treatment sludges (commonly by incineration or land-disposal), and the paper products themselves (10,37,66,67,85,88,98,99,102).

In 1989, cumulative discharges to Canadian receiving waters by bleaching pulp mills have been estimated at 1,000,000 tons (9); even if persistent, toxic and/or bioaccumulative substances make up only a small percentage of these total organochlorine discharges, these are highly significant releases. The chlorine content of bleached paper is second only to PVC as a source of chlorine to waste incinerators in North America (22); dioxins and other persistent
Appendix B

toxic substances have been detected in the emissions from incinerators for sludge from bleached pulp mills.

Unbleached pulp mill effluents also contain a wide variety of organic compounds and heavy metals, which may also be toxic to fish and other aquatic organisms (10,35-37,40,93-97). Effluents from bleached mills contain these compounds plus the chlorinated byproducts of chlorine bleaching, many of which are toxic, persistent, and/or bioaccumulative (9,10,35-37,63-70,72,76,82,83,86-92,97,100). The non-chlorinated organic compounds in unbleached mill effluents are not known to be highly persistent or bioaccumulative; however, they have been associated with biological responses in fish, such as the induction of liver detoxification enzymes, although with (sometimes considerably) less severity than in fish exposed to bleached mill effluents (40,96,97).

The finding that unbleached mill effluents can cause biological effects underscores the need to move towards closed-loop effluent-free mills; such changes can be made only if chlorine is not used (37,38). When chlorine bleaches are eliminated, many process loops can be closed, effluents eliminated, and water consumption and discharges substantially reduced. Lower quantities of treatment sludges are also generated, with far lower degrees of contamination, thus lowering treatment and disposal costs and impacts. Moreover, caustic soda that would otherwise have been discharged can be recycled, thus reducing chemical costs, eliminating the energy consumption associated with caustic production, and lowering total demand for caustic, a necessary parallel action in the phaseout of chlorine.

Availability of Alternatives

Pressure to reduce the emission of chlorinated organic compounds, initially focused on dioxins and furans, has led pulp mills to make a number of process changes, including decreasing the use of chlorine in general, and elemental chlorine in particular. From 1988 to 1991, elemental chlorine use in Canada has been cut almost in half (39). Trade predictions are for continued declines in the industry consumption of chlorine in North America, Scandinavia, and Europe. Totally chlorine-free pulps are being manufactured on an increasing scale, as are recycled fibers with mechanical pulp (38).

The alternative technologies to produce high-quality paper without chlorine or chlorine-based compounds have been developed and are in use throughout the world, including the following:

- Manufacture and use of unbleached, off-white paper for most uses.
- Improved housekeeping (better debarking, washing and chipping methods).
- Extended delignification, rapid displacement heating, modified continuous cooking, and solvent pulping to remove more lignin before bleaching.
- Oxygen and hydrogen peroxide pre-bleaching.
- Oxygen-based bleaching, including oxygen, ozone, and hydrogen peroxide.
- Addition of naturally produced enzymes during bleaching to improve the performance of oxygen-based bleaching.

Also, 100% substitution of elemental chlorine with chlorine dioxide substantially reduces the amount of organochlorines in pulp and paper mill effluent (99). However, the extent to which this achieves the goal of zero discharge over the life cycle has not been demonstrated.

These methods are now in use in mills throughout the world for production of numerous types and grades of pulp and paper, including the highest quality market pulp. Twenty six mills worldwide are now producing totally chlorine-free market pulp, including 17 that make kraft pulp. The majority are in Scandinavia, with a few in other nations. Three mills in Canada are now producing totally chlorine-free market pulp, and one U.S. kraft mill in California recently announced plans to market high-brightness chlorine-free kraft pulp produced through a combination of the methods listed above.

For most applications, equal brightness, strength and other qualities are now being achieved without chlorine or other chlorine-based bleaches. Rapid development of alternative bleaching methods indicates that, within a short time, any remaining technological barriers to full use of chlorine-free papers will probably be eliminated. Der Spiegel, the largest-circulation top-quality news magazine in Germany, is now printed on totally chlorine-free paper, as are numerous other publications.

Implementation of Alternatives

The following measures are available to a sunset program:

- Sunset permits for pulp mills, setting timelines for the reduction and eventual elimination of chlorine and chlorine-based bleaches.
- Other measures, including consumer education and government procurement policies to accelerate demand for chlorine-free paper products; surcharges on chlorine-bleached papers; economic incentives to mills to invest in chlorine-free processes.

The socio-economic impacts of implementing
these alternatives do not appear prohibitive, given the current trend to eliminate chlorine use in Europe. Following an initial investment, production of chlorine-free pulp involves lower chemical costs, lower costs for treatment and disposal of organochlorine-contaminated effluents and sludges, and -- if process loops are closed -- additional cost savings.

Demand for totally chlorine-free pulps is growing in both European and American markets. Mills that invest to meet changing market demand will be far better positioned to compete with European and other mills over the next decade. Because of the initial investment involved, it may be necessary for the Parties to ensure that regulatory policies apply to mills through the U.S. and Canada rather than just to those in the Great Lakes region.

OTHER CHLORINE USES

A brief overview suggests that for most uses, a similar picture emerges: alternatives are currently available and practical to allow the phaseout of most major uses of chlorine.

Chlorinated Solvents

Chlorinated solvents account for an estimated 10% of chlorine use in the U.S. Used for cleaning, coating, and extraction in manufacturing industries, the chlorinated solvents are ubiquitous as atmospheric and groundwater contaminants. It has been estimated that almost the entire quantity of chlorinated solvents used ends up being released into the atmosphere. Much of that which is controlled ends up being incinerated as waste. The persistence and toxicity of chlorinated solvents and their chlorinated breakdown products (i.e. vinyl chloride, chloroacetic acids) in the air and groundwater have been well documented. Worker and community exposures to air emissions of these volatile chemicals are also of serious concern, and halogenated solvents are primary causes of depletion of the stratospheric ozone layer. Chlorinated solvents are also a primary source of chlorine feed in hazardous waste incinerators.

Total demand for other chlorinated solvents is also expected to decline over the next decade as industries seek to minimize costs for chemical procurement, disposal and liability and as concern over worker and community health effects grows. Already, major manufacturers, such as IBM and GE have announced plans to phaseout the use of chlorinated solvents.

Alternatives to chlorinated solvents include process changes to eliminate the need for cleaning with solvents; water-based cleaning, coating and extraction; use of non-chemical cleaning agents such as soaps and citrus-based chemicals; and mechanical or dry cleaning and coating processes. U.S. EPA is now investigating a solvent-free, steam-based alternative to dry cleaning (the major use for perchloroethylene) that is now in use in England.

Chlorinated solvent use is already declining. The ozone-depleting solvents and refrigerants chlorofluorocarbons, hydrochlorofluorocarbons, carbon tetrachloride, and 1,1,1-trichloroethane are already subject to worldwide phaseout agreements. In Sweden, carbon tetrachloride, methylene chloride, trichloroethylene, and 1,1,1-trichloroethane have been placed on phaseout timetables.

Pesticides

Pesticides account for only an estimated 2% of total chlorine use but, because they are intentionally introduced directly into the environment are responsible for severe contamination on a global basis. While some chlorinated pesticides have already been restricted, others, such as alachlor, atrazine, and 2,4-D remain in widespread use. Of the top five pesticides used in the U.S. today, all are chlorinated (atrazine, alachlor, 2,4-D, metolachlor, and dichloropropene). These pesticides and their breakdown products are also ubiquitous contaminants of surface waters, groundwaters, and food supplies. In addition, pesticide manufacture - a complex, multi-step process -- tends to be associated with the production of large quantities of halogenated wastes.

Pesticides are a major use for the aromatic chlorinated feedstocks which are themselves associated with significant persistence and toxicity and with the production of high quantities of the byproducts of greatest concern, such as hexachlorobenzene, PCDD, and PCDFs. Some non-chlorinated pesticides, such as the highly toxic parathions, paraquat, and others, are made via chlorinated intermediates that are associated with the production and release of persistent, toxic chlorinated wastes.

The alternatives to synthetic pesticides are well documented and are in use by organic farmers throughout North America. Methods include improved crop choice, rotation and mixing; maintenance and introduction of natural predators; and use of biological pesticides. These methods often involve greater labor costs which are offset by reduced costs for chemical procurement. In a 1989 review, the U.S. National Academy of Sciences found that chemical-free agricultural methods can result in yields and productivity as high or higher than pesticide-intensive farming. That review recommended a national program to remove financial and political barriers that encourage farmers to rely on pesticide-based methods.

There is ample precedent for restricting or banning the manufacture and use of persistent toxic pesticides, especially organochlorines. Such policies could be extended, on phaseout timetables, from individual compounds to the class of pesticides that contain chlorine, with exceptions made according to the principle of reverse onus.

Appendix B
Chemical Intermediates

The use of chlorinated organics within the chemical industry to produce chlorine-free products, such as polyurethane and epoxy resins, accounts for as much as 20% of chlorine use in the U.S., and a lower amount in Canada. Although the final products do not contain chlorine, these production processes involve the generation of large quantities of chlorinated wastes and byproducts, along with environmental releases and worker exposures to chlorinated feedstocks and their wastes (17).

PCDD/Fs have been detected in chlorinated intermediates and the products made from them, including epichlorohydrin, chlorobenzenes, and phthalocine dyes made through chloro-aromatic intermediates. Many of the intermediates -- such as phosgene and epichlorohydrin -- are themselves recognized for their extreme toxicity. Based on the well-documented generation of highly persistent toxic byproducts, the chlorinated aromatic intermediates (chlorobenzenes and derivatives) may be top candidates for prioritization within this sector.

This sector tends to be highly specialized, but alternatives are known to be available for at least some major uses. For instance, Dow Chemical uses approximately 8% of all the chlorine produced in the U.S. to manufacture propylene oxide (used for onward production of polyurethane, brake fluids, and other chemicals); however, another major U.S. chemical company, ARCO, produces propylene oxide through a chlorine-free oxidation process using the catalyst tert-butyl peroxide. Monsanto recently developed an organic reaction to produce aromatic amines in a way that eliminates the need to use halogenated organics (104).

Phosgene (used primarily to produce isocyanates for polyurethane production) and epichlorohydrin (used to produce epoxy resins and other chemicals) each account for about 5% of total chlorine use in the U.S. As for propylene oxide, because chlorine does not appear in the final product, there is no theoretical reason that other methods of chemical synthesis -- including oxidation with organic or metal catalysts and electrochemical oxidation -- cannot substitute for chlorine-based process. For instance, dimethyl carbonate substitutes for phosgene and metal-catalyzed oxidation substitutes for epichlorohydrin are in use or development.

Continued research and development in this area can be expected for those uses for which alternatives are not now established. Such research would be hastened in the anticipation of sunset timetables for these chlorinated intermediates.

Disinfection

Disinfection of water and wastewater accounts for about 5% of total chlorine use in the U.S.; of this, an estimated 4% is wastewater treatment, with less than 1% being used for drinking water disinfection.

When chlorine is used as a disinfectant for wastewater or drinking water, hundreds of chlorinated organic byproducts result, including toxic and persistent chlorinated acids, aliphatics, ketones, and aromatics, such as chlorophenols and chlorobenzenes. In addition, a significant portion of the byproducts are composed of unidentified compounds. Emerging evidence suggests that exposure to these byproducts may be linked to increased incidence of certain cancers, birth defects, and developmental toxicity (see Appendix D); further studies are needed to confirm and clarify the role of chlorinated byproducts in these and other possible effects.

Alternative disinfection methods are available to reduce or eliminate chlorine use in this sector. For wastewaters, available alternatives that cut chlorine use to zero are in worldwide use. The most common methods are ultraviolet and ozone treatment. Ozone is an extremely effective disinfectant, but the process is energy intensive and produces chemical byproducts that, though apparently less persistent than those produced by chlorination, may be problematic from a health and environmental perspective. Ultraviolet (UV) treatment is also an effective disinfectant, based on the destruction of bacteria and viruses with a narrow frequency of intense light; no chemical byproducts are produced, and energy requirements are less than those for chlorine.

Several hundred wastewater treatment plants in the U.S. and Canada have installed UV systems and eliminated chlorine in the last decade. Capital costs are estimated to be equal to or less than those for chlorine, and operating costs are lower.

These alternatives are effective disinfectants for drinking water, as well, and can replace chlorine for in-plant disinfection. However, where drinking water has a high content of organic matter and travels through long delivery systems, a residual is necessary to prevent regrowth of pathogens after initial treatment. Neither ozone nor UV provides such a residual, and many North American treatment works that have installed these methods must continue to use chlorine for residual disinfection. In Europe, where several thousand plants use ozone or UV systems, the use of sand- or carbon-filtration to remove organic matter and more carefully designed delivery systems make the chlorine residual unnecessary.

Thus, alternative disinfectants appear feasible to eliminate the use of chlorine entirely for wastewater treatment and for in-plant disinfection of drinking water. Smaller amounts of chlorine will continue to be necessary until larger changes are possible in water treatment and delivery systems. This "residual" chlorine use that should be maintained, however, represents a very small percentage of chlorine use.
CONCLUSION

Chlorinated organic persistent toxic substances represent a unique class of compounds. When implementing the strategy to achieve the Agreement’s goals of virtual elimination, it is necessary that these substances be treated as a class of chemicals. The properties of these substances which require that they be treated as a class include their inherent toxicity, the fact that they are virtually entirely noxious or poisonous to natural systems, and the fact that roughly half of the toxic chemicals found in the Great Lakes are chlorinated. Both the Commission and its Science Advisory Board have recognized the importance of treating chlorine as a class of persistent toxic substances, rather than attempting to deal with them individually.

This analysis indicates the utility of applying a use tree to investigate phasing out an industrial feedstock chemical such as chlorine. The use tree analysis indicates the wide variety of uses of chlorine. It also indicates the importance of reducing industrial demand for caustic soda. This can be accomplished in a number of ways, including through conservation and recycling, through the use of alternative alkalis or sodium sources, and by producing caustic soda through methods other than the chlor-alkali process.

The information in this review suggests that phasing out many industrial uses of chlorine is practical and feasible. For the two main uses of chlorine, production of PVC and chlorine bleaching in the pulp and paper industry, alternatives are available. In fact, it is encouraging to note that many European and North American firms are currently making this transition.

The strategy recommended in this review includes issuing sunset permits for current industrial users of chlorine. These permits would specify the date in the future after which no chlorine could be used in the process and would include progressively more stringent limits to reduce chlorine use (and release of organo-chlorine wastes) in the interim.

The Commission recommended in its Sixth Biennial Report that the Parties develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks. This analysis provides a framework for implementing that recommendation and begins to answer many of the questions raised by the recommendation. Most importantly, this report to the Task Force indicates that phasing out many industrial uses of chlorine is practical, feasible, necessary and should be accomplished by the U.S. and Canada.

REFERENCES


32. Theisen, J. “Untersuchungen der moglichen Umweltgefahren beim Bran von Kunststoffen (Examination of possible environmental hazards caused by plastic fires), German EPA, July 1991.


Appendix B


APPENDIX C

ECONOMIC INSTRUMENTS AND VIRTUAL ELIMINATION
A Report to the Virtual Elimination Task Force

DISCLAIMER
The views expressed in this appendix do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission.
ECONOMIC INSTRUMENTS AND INCENTIVE IMPLICATIONS
A Report to the Virtual Entrepreneur Task Force

DEVELOPMENT
The report outlines the economic instruments and incentives for entrepreneurial
development and showcases the economic implications in the context of entrepreneurship.

PRELIMINARY
This preliminary section provides an overview of the report's objectives and
findings.
Appendix C

ECONOMIC INSTRUMENTS AND VIRTUAL ELIMINATION
A Report to the Virtual Elimination Task Force

FOREWORD

The Task Force investigated the potential usefulness of economic instruments (or "incentives") to help achieve virtual elimination and zero discharge of persistent toxic substances, specifically:

- Application of economic instruments to PCBs, mercury, and chlorine. Initially presented in the Task Force's Interim Report (1), this assessment complements the case studies presented in Appendices A and B.

- Application of selected economic instruments (such as input taxes or permits, and effluent or discharge taxes) to incinerators and polyvinyl chloride (PVC). These findings are based on a report (2) tendered by a contractor. Throughout his work, the contractor was guided by the Task Force's Economic Subgroup.

The intent of selecting diverse examples was to identify generic considerations that would be applicable to other persistent toxic substances and to a range of economic sectors. However, time constraints and other considerations precluded adequate Task Force consideration of the advice received to date. The perspective presented below presents insight into economic instruments and their application to persistent toxic substances in a virtual elimination context. The Task Force cautions, however, that the general perspective, the discussion about obstacles, and the views about incinerators and PVC have not been considered or adopted by the Task Force as a whole and must not be taken or construed as endorsed by the entire Task Force or its Economic Subgroup. The Task Force trusts, nonetheless, that these perspectives will prove useful in others' future deliberations.

GENERAL PERSPECTIVE

Economic instruments may not be ideally suited to persistent toxic substances because of the ability of these substances to persist in the ecosystem, bioaccumulate in living organisms, and cause biological injury; strict regulation and bans may be more appropriate. However, economic instruments can play a useful complementary role, in conjunction with other elements of the virtual elimination strategy to:

- Reinforce prevention and sunset initiatives by influencing behaviour through the price system (e.g. effluent or discharge taxes and taxes on inputs).

- Reinforce regulations by providing penalties for compliance failures.

- Accelerate research and implementation of destruction technologies for substances like PCBs.

- Introduce tradeable permits on inputs, within a regulatory regime, declining over time to zero ("sunset permits") or an irreducible minimum ("de minimis permits").

- Provide a pool of revenue used to finance the development and adoption of substitutes or alternatives, and remediation activities. This carrot-and-stick approach can provide a "program bubble" enabling an organized transition away from persistent toxic substances.

Broadly, economic instruments consisting of emissions trading programs may not be appropriate for persistent toxic substances, since emissions trading is targeted at reduction rather than elimination. However, a trading program that includes staged reductions in emissions, en route to virtual elimination and zero discharge, may be feasible. Emissions trading has never been applied to persistent toxic substances and, in general, is philosophically opposed by the Task Force as an element of the virtual elimination strategy. Such instruments can be viewed as legitimizing the buying and selling of rights to contaminate the environment and therefore antithetical to the virtual elimination strategy. All releases of persistent toxic substances are significant because their inherent properties (persistence, bioaccumulation, and continuing biological injury) render these substances a special case.

Economic incentives, in themselves, likely are not sufficient to reach the virtual elimination goal. That goal and the philosophy or tactic of zero discharge from human activities, is a given end, based on the stated policy of the Parties signatory to the Agreement. Economic instruments are, however, a possible means to help achieve that stated end.

ECONOMIC CONCEPTS AS OBSTACLES

One obstacle is that many stakeholders generally do not know or recognize the special status of persistent toxic substances and the underlying rationale for the virtual elimination policy, even within the lead environmental agencies of the Parties. This obstacle
Appendix C

- Appropriate in situ remediation (e.g. contaminated sediment) could also be encouraged in a variety of ways, including polluter pay taxes to a superfund, green bonds, and a natural resource amenity tax to capture some of the development windfall in restored areas.

- Incentives such as effluent fees on discharges, combined with tradeable permits on PCBs presently allowed in use, may also be effective. Regulations would gradually increase the effluent fees on discharges. Concurrently, the amount of PCBs allowed in use, together with equivalent tradeable permits, would be limited with a predefined schedule declining to zero over time.

ECONOMIC INSTRUMENTS AND MERCURY

Mercury, which occurs naturally, is usually not readily available to the food chain because of its form and location. However, anthropogenic use and release greatly increase its availability. Many uses can be curtailed or eliminated, but the practical reality is that some sources (e.g. from fossil fuel combustion) cannot be phased out in any practical time frame. Economic instruments may help accelerate elimination toward the zero target, to reduce the use of mercury and mercury-containing products to the absolute minimum.

- To stop the production and use of mercury, taxes could be levied on its production. This would partially recover damages and encourage pollution prevention through substitution. Also, taxes could be levied on intermediate and final products containing mercury, as well as on manufacturing activities that use mercury. Revenues generated could be used for cleanup, rehabilitation, and development of substitutes.

- To encourage life cycle management and the development of substitutes, a deposit/refund system could apply to all final or intermediate products containing mercury, and all products using mercury in their manufacture.

- An effluent charge could be levied on electric utilities, smelters, and incinerators. Revenues could be used for remedial action (e.g. contaminated sediment), protection, and development of substitutes.

- Incentives could be provided for consumer information, education and awareness raising programs to influence demand for alternative products.

ECONOMIC INCENTIVES AND CHLORINE

The general assessment study focused on the pulp and paper industry as a major user of chlorine. A large number of chlorinated organic chemicals are produced in bleaching operations, of which only 5-10% have been identified. Some authorities suggest that the observed toxic effects of pulp and paper effluents are cumulative, controlled by the sum of the effects of perhaps 50 individual chemicals. Therefore, the identification of which specific chemicals cause specific toxic effects is not generally possible. Nonetheless, the use of chlorine as a precursor to these chlorinated organic substances would provide a case to eliminate the use of chlorine in the pulp and paper industry.

Alternative chemicals and substitute processes are available, and others are being developed. Economic incentives could help aid and finance the phaseout and changeover.

- Implement a tax on chlorine and/or chlorine dioxide. The revenue could be used for environmental protection purposes, and would speed the shift to already existing substitute processes.

- Implement a tax on chlorine bleached or processed pulp and paper products.

- To implement an orderly and flexible phaseout of chlorine use, institute a specified schedule of reductions to the sunset zero.

- institute an effluent charge, based on an appropriate measure of the quantity of chlorinated organic material in the mill effluent.

- Financial enforcement incentives (such as noncompliance fees and financial performance bonds, payable when regulations are not met) could support regulations for such chlorine-produced byproducts as 2,3,7,8-TCDD and 2,3,7,8-TCDF.

- Governments can influence demand for nonchlorinated paper products, through purchasing policies, as well as public information and education.

APPLICATION OF ECONOMIC INSTRUMENTS TO INCINERATORS AND POLYVINYL CHLORIDE

Background

The Virtual Elimination Task Force retained the services of a contractor to design, evaluate, and recommend a specific program of economic instruments. That program was to build on previous work
and be applied to case studies selected on the basis of a problem analysis and definition that focused on identifying the major sources of five of the 11 Critical Pollutants (Table 1): mercury, PCBs, hexachlorobenzene, 2,3,7,8-TCDD, and 2,3,7,8-TCDF.

In this problem analysis and choice of indicator substances, it was also noted that chlorinated hydrocarbons and metals or metallic substances, as chemical classes, make up more than half of the Water Quality Board’s 1986 Working List of [362] Chemicals in the Great Lakes Basin (3), and a substantial proportion of other lists, including lists issued by the Ontario Ministry of the Environment and the US. Environmental Protection Agency, for example, the Great Lakes Initiative, the 33/50 Program, and other “lists” for which criteria based on health concerns have been set.

Based on this problem analysis (4), further assessment and program design were limited to two case studies chosen from what were identified as the human activities that are the major sources of these critical pollutants:

- Incineration of municipal and industrial waste (in particular, products containing chlorinated hydrocarbons) and sewage sludge.
- Fossil fuel combustion (particularly coal and wood).
- Production, use, and disposal of chlorine and chlorine-containing compounds.
- Sediments and old landfills.
- Leaks of PCBs from transformers and storage sites.

The case studies chosen from these activities were the use of chlorine in the production of polyvinyl chloride (PVC) and discharges from incinerators. These studies were to design and evaluate a program of economic instruments consisting of input taxes (or permits) on chlorine used in PVC production, and emission fees or discharge taxes levied on incinerators. The case studies are examples, and represent both the input and output side of the product and process life cycle that generates persistent toxic substances.

The primary focus was on incentives for actions specific to the pollution prevention means of zero input, as opposed to the traditional pollution control or treatment mode. The PVC input tax is intended to discourage the use of chlorine generally, but exemplary, as an input in the production of plastics. The incinerator emission tax is intended to encourage source separation, and prevent the inclusion of persistent toxic substance precursors in material designated for incineration. Both instruments focus on prevention, but from different ends of the life cycle. The material presented below is based on the report submitted by the contractor (2).

### The Basis For the Instrument

Ideally, in determining the amount of the input or discharge taxes, consideration would be given to direct and indirect subsidies, and so-called “avoided cost” benefits. These are provided by the status quo free market pricing structure that favours the use of persistent toxic substances and their continued input into the environment. For example, the regulation of chemical pollution, and programs to clean up problems caused by persistent toxic substances, just by themselves, account for very substantial annual costs imposed on governments and taxpayers.

The subsidies could include electrical energy costs, and hydrocarbon feedstock prices that are highly favourable compared to other sectors of the economy, including “competitive” or alternative products or processes. There could also be subsidies in the form of tax incentives, like accelerated depreciation on the purchase of machinery and equipment (favouring highly capital-intensive activities), and exemptions from sales tax.

For an example pertinent to the first case study, regulations that require or encourage permanent incineration facilities provide waste generators with “avoided cost” advantages inherent in relatively inexpensive and liability-free waste disposal methods, that are also free of any environmental damage or cleanup cost accounting (such as future taxing against such known costs).

Incinerators may be given the same, or more favourable, capital-cost allowance-tax treatment as an investment in reduction or recycling (which are likely less capital intensive), or another more benign producer good. Such waste disposal economics also means that the original producers of the inputs or products now requiring disposal activities, have no incentive to change, and have an effective subsidy advantage over alternatives, prevention technologies, and other competing means of providing what the society really wants.

The other case study considers the substantial production, use and ultimate disposal of products that involve the use of chlorine or chlorine-containing substances. The specific example looks at PVC and related additive substances, all of which are human activities that result in inputs of persistent toxic substances to the environment, including several of the 11 Critical Pollutants. These related activities may be subsidized by unaccounted-for environmental damage, remediation, and cleanup costs. Past experience indicates that this involves cost and risk shifting to the future and to society at large. Such costs and risks have increased societal
overhead and public expenditure, which either results in higher taxes, a larger deficit, or cost-cutting pressures elsewhere.

The research and detailed accounting for all these possible subsidies and avoided costs was beyond the scope of the Task Force’s investigation. Therefore, another approach to calculating the amount of the input or discharge tax was taken by considering the following.

Essentially all of the uses of PVC have substitutes in the form of glass, metal, paper, and non-chlorinated polymers. Furthermore, incineration has alternatives in waste disposal activities. It is probable that these alternatives are at a cost disadvantage, at least part of which is the “avoided cost” subsidy given to PVC and incineration. Therefore, the “tax price” should approximate the extra, direct cost involved in converting to the alternative substance, product, or process, including waste disposal processes, that approach the zero input goal for persistent toxic substances.

**Context for Assessing the Instruments**

To assess the use of economic instruments to reduce emissions from incinerators and from the production, use, and disposal of PVC, two programs, in addition to the taxes on municipal solid waste incinerators and PVC, were considered:

- A program of regulatory instruments: prescriptions of laws and specific technology.
- A pollution prevention program: information, moral suasion, and voluntary actions.

The effectiveness and direct costs of a number of actions representative of pollution prevention (elimination, reduction, separation, and substitution) and regulation-mandated technology fixes were estimated. These were then used to develop “least-cost” curves, from which the first estimate of the “tax price” schedules (referred to above) or possible “tradeable permit” schemes were derived.

The study takes the virtual elimination policy as a given, and acknowledges the strong reasons for adopting zero discharge as optimal. Consideration of health and environmental damage from persistent toxic substances and, therefore, the “benefits” of virtual elimination and zero discharge, are explicitly excluded. Economic analysis is done in terms of cost-effectiveness, and not the economic efficiency calculations of benefit-cost analysis, as discussed above. Other criteria considered include environmental effectiveness, equity, administrative feasibility, and stakeholder acceptability.

Broader macro-economic impacts and the dynamic, structural change impacts are not extensively considered. Except in exceptional circumstances, the direct impacts are more targeted or concentrated. On balance, the actions really substitute one set of human activities for another. In the absence of adaptation and innovation by the sectors targeted for economic instruments towards the opportunities of the “new” activities, there will be sectoral shifts to balance out.

Given the relative capital and labour intensities of the “alternatives,” the net employment impacts are likely to be positive, both in terms of number and quality of jobs. The virtual elimination strategy, and the general pollution prevention actions that implement it, involve creative, knowledge-intensive activities that are emerging as economic strengths.

The new activities will spur sustainable development, which is a form of economic development that enhances the resource base rather than degrades it. There will likely be a substantial netting out or balancing of the long-run adjustment costs, as there is a need to account for the opportunity cost savings involved in the “capital switching” (capital accumulation in the “new” activities, and capital decumulation in activities that generate persistent toxic substances) that will occur. The “tax” costs of the incentives to business (near zero for some actions), as revenue to governments, can be recycled as a “program bubble” to help finance the transition, including mitigation.

The broader cost impacts are largely diffused, and the spinoff effects and structural changes are likely to be of more concern with regard to distributional or equity issues. However, structural changes, of much larger net scale, are going on all the time for purely financial and other reasons. In considering these issues, it is appropriate to recall the positive health and environmental implications and the sustainable development aspects.

**Economic Incentives and Incinerators**

Incinerators are a significant source of each of the persistent toxic substances selected for consideration. As well, they are a source of numerous other substances referred to as PICs, or products of incomplete combustion (including many from the Water Quality Board’s Working List) (3) and many of which are unidentified and may be persistent toxic substances.

The five persistent toxic substances used as indicator substances were weighted and aggregated into a so-called “gram-equivalent” composite index using a methodology described in the study report (2). A number of prevention and regulatory actions for reducing persistent toxic substances from incinerators specifically applied to those located in the Great Lakes basin, as well as diversion to landfills and their effectiveness and costs, were developed and ranked (Tables C-1 and C-2). Based on these esti-
mates of costs per gram-equivalent reduction, a sequence of implicit tax increments and corresponding progress towards virtual elimination was calculated from the cost curve (Figure C-1). The major findings, taken as indicative rather than exact, include:

- Roughly 25% of gram-equivalent emissions (primarily mercury) could be eliminated at zero cost to incinerator operators, using prevention actions aimed at reduction and substitution implemented by manufacturers. Announcement of an upcoming discharge tax could stimulate incinerator operators to encourage these actions without having to actually impose the tax at that time.

- A discharge tax of about $1 per gram-equivalent could reduce the composite gram-equivalent emissions to air by about 85%. This tax amount could encourage source separation and diversion to other methods (e.g. recycling, composting, or some specific waste to landfills) and would make advanced pollution control attractive in almost all cases. Problematically, air pollution control is not a multimedia reduction, as the ash and wastewater streams are increased, not reduced, and certainly not eliminated.

- There is a large shift above $1 per gram-equivalent in the level of the tax required to eliminate emissions. This warrants attention if there is a desire to discourage or ban new incinerator construction and to phaseout existing ones, in favour of other waste management options based on pollution prevention, and landfilling what remains.

- A discharge tax of about $30 per gram-equivalent could increase the reduction in emissions to about 95%. This tax amount would result in incinerator operating costs alone being in excess of landfilling costs, and would encourage diversion to landfill.

- A discharge tax of $45 or more per gram-equivalent generally makes pollution prevention, source elimination, reduction, substitution, and separation, and then landfilling, more attractive than incineration. This would, of course, reduce releases of persistent toxic substances from municipal incinerators by 100%.

- Revenues from the tax are estimated to peak at about $20 per gram-equivalent, generating about $350,000,000 per year. At this tax level, it is estimated that emissions to air are reduced by about 90%. Beyond that tax level, revenues decline to zero at about the $45 per gram-equivalent rate.

- Economic instruments applied to incinerator emissions would likely encourage greater application of unit-charge or user-pay systems for municipal waste, combined with pollution prevention and recycling programs. Numerous studies have shown that this can substantially reduce waste generation and management costs. As well, prevention and 3R (reduce, reuse, recycle) programs generally provide more jobs and spur innovation. The high capital costs of incinerators totally discourage these alternatives as they lock in the need for trash to burn for long periods.

- A regulatory program that would lead to virtual elimination of persistent toxic substances from incinerators would likely entail a prohibition on new incinerators, with a grandfathering of existing ones until they exhaust their useful life. Ontario has prohibited new municipal waste incinerators. Economic instruments could be used to accelerate, and possibly help finance the phaseout of existing ones.

- The cost of new incinerators and new landfills are roughly comparable; thus, the goal of virtual elimination ought to ensure that new incinerators are not constructed.

- Stakeholder consultations indicated a consensus that there is a need to control emissions of persistent toxic substances from incinerators. Industry and government representatives contacted favoured regulation and emission standards combined with information and moral suasion, whereas environmental organizations preferred a phaseout.

- The discharge tax program alone was viewed as the least desirable. To be effective would require long lead times, and a recycling of the revenues to programs designed to further the virtual elimination goal in the municipal waste sector.

- The main obstacle to feasibility of any program, whether regulation or economic instruments, concerns the feasibility of continuous monitoring of persistent toxic substance emissions. There is great variability in emission rates. Metals, organic substances, and products of incomplete combustion are not routinely monitored, and sampling trains are limited. Presently used proxies like carbon monoxide are not considered adequate.

- The consultant suggested (2) that an emissions trading program for incinerators appears to be the most feasible and advantageous, although such schemes are philosophically generally opposed by the Task Force since they entail continued emissions and not virtual elimination.
# Table C-1
Effectiveness and Costs of Action for Reducing Persistent Toxic Substances from Incinerators

<table>
<thead>
<tr>
<th>Action type/action</th>
<th>Compound affected</th>
<th>Potential reduction (tE)</th>
<th>Average unit cost ($)</th>
<th>Action code&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source reduction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce the Hg content of paint</td>
<td>Hg&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.2</td>
<td>$0</td>
<td>Paint1</td>
</tr>
<tr>
<td>Reduce the Hg content of batteries</td>
<td>Hg</td>
<td>17.8</td>
<td>$0</td>
<td>Battery1</td>
</tr>
<tr>
<td>Use batteries with low Hg levels</td>
<td>Hg</td>
<td>5.7</td>
<td>$0</td>
<td>Battery2</td>
</tr>
<tr>
<td>Landfill instead of incinerating waste</td>
<td>All&lt;sup&gt;c&lt;/sup&gt;</td>
<td>230.6</td>
<td>$2,733,795</td>
<td>Landfill1</td>
</tr>
<tr>
<td><strong>Product substitution</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce mercury content of other products</td>
<td>Hg</td>
<td>14.4</td>
<td>$0</td>
<td>Other1</td>
</tr>
<tr>
<td><strong>Source separation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remove paper, paper products and wood from incinerator feed</td>
<td>Cl Org&lt;sup&gt;c&lt;/sup&gt;</td>
<td>NA</td>
<td>NA</td>
<td>Paper1</td>
</tr>
<tr>
<td>Remove polyvinyl chloride from incinerator feed</td>
<td>Cl Org</td>
<td>NA</td>
<td>NA</td>
<td>PVC1</td>
</tr>
<tr>
<td>Remove food, yard and other organic wastes from incinerator feed</td>
<td>Cl Org</td>
<td>NA</td>
<td>NA</td>
<td>Food1</td>
</tr>
<tr>
<td>Collect and recycle Hg-containing paints</td>
<td>Hg</td>
<td>5.3</td>
<td>NA</td>
<td>Paint3</td>
</tr>
<tr>
<td>Collect and landfill Hg-containing paint</td>
<td>Hg</td>
<td>2.4</td>
<td>$7,066</td>
<td>Paint2</td>
</tr>
<tr>
<td>Collect and landfill other Hg-containing products</td>
<td>Hg</td>
<td>2.7</td>
<td>$9,421</td>
<td>Electric1</td>
</tr>
<tr>
<td>Collect and recycle Hg-containing batteries</td>
<td>Hg</td>
<td>33.5</td>
<td>$9,893</td>
<td>Battery4</td>
</tr>
<tr>
<td>Collect and landfill Hg-containing batteries</td>
<td>Hg</td>
<td>33.5</td>
<td>$14,132</td>
<td>Battery3</td>
</tr>
<tr>
<td><strong>Pollution control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use activated carbon adsorption</td>
<td>Hg</td>
<td>86.2</td>
<td>$103,642</td>
<td>CA</td>
</tr>
<tr>
<td>Use sodium sulphide injection</td>
<td>Hg</td>
<td>136.3</td>
<td>$103,642</td>
<td>Na&lt;sub&gt;2&lt;/sub&gt;S</td>
</tr>
<tr>
<td>Use spray dry scrubbers and fabric filters</td>
<td>All</td>
<td>124.6</td>
<td>$764,932</td>
<td>SD/FF</td>
</tr>
<tr>
<td>Use dry sorbent injection with fabric filters</td>
<td>Hg</td>
<td>95.4</td>
<td>$999,149</td>
<td>DSI/FF</td>
</tr>
</tbody>
</table>

Notes:

<sup>a</sup> - To facilitate cross compound comparisons, units and costs are in tE or tonnes equivalent, based on equivalency factors. See Reference (2).

<sup>b</sup> - More details on actions are in Reference (2), ordered by action code.

<sup>c</sup> - Cl Org refers to chlorinated organics (polychlorinated dibenzo-p-dioxin, polychlorinated dibenzofuran, hexachlorobenzene, PCB); Hg is mercury; All refers to both chlorinated organics and mercury.

<sup>d</sup> - Based on the average unit cost for all municipal solid waste incinerator facilities in the Great Lakes Basin. Unit costs for individual facilities vary.
### Table C-2
Incinerator Actions Ordered by Source and Economic Attractiveness

<table>
<thead>
<tr>
<th>Sourcea</th>
<th>Action typec</th>
<th>Incremental unit cost ($/tE)d</th>
<th>Reduction (%)</th>
<th>Cumulative reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sourcesb</td>
<td>Mercury reduction</td>
<td>0.00</td>
<td>26.9</td>
<td>26.9</td>
</tr>
<tr>
<td>Sources 26, 25, 3, 12</td>
<td>Pollution control</td>
<td>0.04</td>
<td>1.3</td>
<td>28.2</td>
</tr>
<tr>
<td>Sources 31, 28, 23, 32, 9, 21, 30, 27, 18, 29, 4</td>
<td>Pollution control</td>
<td>0.05</td>
<td>2.6</td>
<td>33.2</td>
</tr>
<tr>
<td>Sources 8, 34</td>
<td>Pollution control</td>
<td>0.06</td>
<td>6.7</td>
<td>78.3</td>
</tr>
<tr>
<td>Source 2</td>
<td>Pollution control</td>
<td>0.09</td>
<td>1.7</td>
<td>80.7</td>
</tr>
<tr>
<td>Source 11</td>
<td>Pollution control</td>
<td>0.16</td>
<td>4.8</td>
<td>85.5</td>
</tr>
<tr>
<td>Sources 6, 1, 5</td>
<td>Pollution control</td>
<td>0.17</td>
<td>0.4</td>
<td>86.0</td>
</tr>
<tr>
<td>Source 20</td>
<td>Pollution control</td>
<td>0.20</td>
<td>0.5</td>
<td>87.2</td>
</tr>
<tr>
<td>Sources 33, 17, 19</td>
<td>Pollution control</td>
<td>0.27</td>
<td>0.2</td>
<td>87.4</td>
</tr>
<tr>
<td>Sources 12, 26, 25, 5, 1, 4, 6, 3</td>
<td>Landfill</td>
<td>20.31</td>
<td>0.1</td>
<td>88.3</td>
</tr>
<tr>
<td>Sources 8, 34, 13, 24, 10, 17, 20, 14, 15</td>
<td>Landfill</td>
<td>28.72</td>
<td>0.9</td>
<td>90.4</td>
</tr>
<tr>
<td>Sources 21, 9, 19, 11, 2, 28, 16, 32, 23, 31</td>
<td>Landfill</td>
<td>41.08</td>
<td>0.1</td>
<td>94.8</td>
</tr>
<tr>
<td>Sources 18, 29, 27, 30, 22, 33</td>
<td>Landfill</td>
<td>44.45</td>
<td>0.3</td>
<td>99.5</td>
</tr>
</tbody>
</table>

Notes:  

- **a** - For details about individual sources, see Reference (2).  
- **b** - Mercury source reduction and product substitution actions are costless. These actions were grouped together and the potential reduction applied to all sources.  
- **c** - More details on individual actions are in Reference (2).  
- **d** - To facilitate cross-compound comparisons, units and costs are in tE or tonnes equivalent, based on equivalency factors. Unit costs for individual facilities. See Reference (2).  

---

**Figure C-1**
Incremental Costs of Achieving Reductions in Emissions from Incinerators  
Source: Reference (2).
A combination of pollution prevention, economic instruments, and regulation would seem the most effective and flexible in practice.

**Economic Instruments and Polyvinyl Chloride (PVC)**

PVC manufacturing is a major use of chlorine and has a number of environmental concerns associated with its production, use, and disposal life cycle, including the co-use, generation, and release of a substantial number of persistent toxic substances, including several of the 11 Critical Pollutants. As noted earlier, the problem analysis and definition underlying the economic instruments work indicated that the production, use, and disposal life cycle of chlorine and chlorine-containing compounds was a major source of the indicator persistent toxic substances.

The scope of the study was only able to include actions specific to the uses of PVC in the building and construction sector, which accounts for about 46% of PVC use in the Great Lakes basin (Table C-3). These results may also be representative of the potential impacts on PVC uses not explicitly considered. Thus, these results are likely lower bound estimates.

The economic instruments program involves applying an input tax on chlorine used in PVC production, with the tax rising over time to discourage PVC use. The program considers the PVC demand and associated chlorine use only in the Great Lakes basin for 1992. All the actions identified to reduce or eliminate PVC use were substitutes, the costs of which were used to provide the first estimate of the appropriate input tax schedule that would lead to virtual elimination. The relative costs of the substitute applications examined were used to derive the least-cost curve (Figure C-2), from which a sequence of tax increments and progress towards virtual elimination were drawn.

The PVC example cannot stand alone. All chlorine uses must be factored into the program. The instruments considered for PVC should be examined for effects on other uses of chlorine.

The major findings, again taken as indicative rather than exact, include:

- About 20% of PVC uses have numerous substitutes already available at less cost than PVC. Therefore, announcement of an input tax program could encourage these actions without having to actually implement the tax at that time.
- An input tax of $2 per kg of PVC could encourage most watermain and sewer pipe applications to switch to substitutes, which involves 25% of PVC use.

Above a level of $2 per kg, there are very substantial to extreme jumps in the level of the tax required to encourage alternatives. This is due, in part, to the restricted set of PVC uses considered.

- At a tax rate of $10 per kg of PVC, most electrical conduit applications could be encouraged to switch from PVC, involving about 42%.
- At a tax rate of $100 per kg of PVC, building and construction uses are unattractive, and almost all (44% of the 46% of the total use that was considered) could be substituted.
- At a tax rate of $300 per kg of PVC, it is likely that very few uses of PVC would remain.

Revenues from a tax on PVC are estimated to peak at about $3 per kg (Figure C-3). The total revenue generated is about $400,000,000 per year. The cumulative reduction in the use of PVC at this tax rate is about 25%.

After a drop, a second peak in revenues (about $325,000,000 per year) arises at about $6 per kg, when a total of about 38% of all PVC use is eliminated.

- At about $10 per kg the tax is expected to eliminate about 42% of total PVC use.
- The tax can be placed at several places in the life cycle of PVC, including input taxes on chlorine, taxes on manufactured PVC itself, and deposits on PVC products to ensure control over disposal practices.
- The impacts on employment would be expected to balance out between the PVC and substitute sectors.
- Short-run cost increases would be diffused throughout the economy. In the long run, there would be capital switching (as noted previously); however, there is a need to account for the opportunity cost savings emergent from the declining sector. As well, costs and prices of the substitutes would normally be expected to move downwards over time, removing some of the initial price disadvantage where it exists.
- The analysis assumes that the substitutes are equally functional. Some examples, like underground irrigation pipe, appear to be exceptions, although the development of alternative plastics should be possible. In general, there is a need in this respect to consider how valuable particular specialized uses for PVC are, considering the hidden costs in persistent toxic substance contamination.
### Table C-3
Actions Ordered by Economic Attractiveness

<table>
<thead>
<tr>
<th>Action code</th>
<th>Description</th>
<th>Reduction in PVC use (%)</th>
<th>Incremental unit cost&lt;sup&gt;b&lt;/sup&gt; ($/kg reduced)</th>
<th>Cumulative reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VINYL3</td>
<td>Building and construction</td>
<td>2.8</td>
<td>38.00</td>
<td>2.8</td>
</tr>
<tr>
<td>SEWER2</td>
<td>Sewer pipes - storm</td>
<td>6.2</td>
<td>1.09</td>
<td>9.0</td>
</tr>
<tr>
<td>WATMAIN9</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>1.00</td>
<td>10.5</td>
</tr>
<tr>
<td>WATMAIN8</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.88</td>
<td>12.1</td>
</tr>
<tr>
<td>WATMAIN5</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.60</td>
<td>13.6</td>
</tr>
<tr>
<td>WATMAIN7</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.55</td>
<td>15.1</td>
</tr>
<tr>
<td>WATMAIN6</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.39</td>
<td>16.7</td>
</tr>
<tr>
<td>WATMAIN4</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.29</td>
<td>18.2</td>
</tr>
<tr>
<td>SEWER1</td>
<td>Sewer pipes - sanitary</td>
<td>3.0</td>
<td>0.21</td>
<td>21.2</td>
</tr>
<tr>
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<td>Water main pressure pipes</td>
<td>1.5</td>
<td>0.48</td>
<td>22.8</td>
</tr>
<tr>
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<td>1.5</td>
<td>1.15</td>
<td>24.3</td>
</tr>
<tr>
<td>WATMAIN1</td>
<td>Water main pressure pipes</td>
<td>1.5</td>
<td>3.26</td>
<td>25.8</td>
</tr>
<tr>
<td>CONDUIT9</td>
<td>Electrical conduits</td>
<td>0.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.31</td>
<td>25.9</td>
</tr>
<tr>
<td>VINYL1</td>
<td>Building and construction</td>
<td>10.0</td>
<td>4.13</td>
<td>35.9</td>
</tr>
<tr>
<td>CONDUIT5</td>
<td>Electrical conduits</td>
<td>0.2</td>
<td>4.50</td>
<td>36.0</td>
</tr>
<tr>
<td>CONDUIT6</td>
<td>Electrical conduits</td>
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<td>5.84</td>
<td>36.7</td>
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<tr>
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<td>5.97</td>
<td>37.6</td>
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<td>6.33</td>
<td>39.3</td>
</tr>
<tr>
<td>CONDUIT7</td>
<td>Electrical conduits</td>
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<td>6.75</td>
<td>40.1</td>
</tr>
<tr>
<td>CONDUIT4</td>
<td>Electrical conduits</td>
<td>0.7</td>
<td>6.95</td>
<td>40.8</td>
</tr>
<tr>
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<td>Electrical conduits</td>
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<td>7.51</td>
<td>41.0</td>
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<td>CONDUIT1</td>
<td>Electrical conduits</td>
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<td>42.0</td>
</tr>
<tr>
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<td>Building and construction</td>
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<td>93.65</td>
<td>44.1</td>
</tr>
<tr>
<td>IRRIG1</td>
<td>Irrigation pipes - underground</td>
<td>2.1</td>
<td>242.08</td>
<td>46.2</td>
</tr>
</tbody>
</table>

**Notes:**
- Action code refers to the coding of Action Information Sheets appended to Reference (2).
- Costs are for reduction in PVC use (1992 Canadian dollars).
- Less than 0.5%.

**Source:** Reference (2).
Appendix C

Figure C-2
Incremental Costs of Achieving Reductions in PVC Use

Source: Reference (2).

Figure C-3
Revenues from a Tax on PVC Use

Source: Reference (2).
• Stakeholder consultations revealed that a combination of all three programs was most effective. This included an input tax on chlorine, combined with a ban on PVC use in building products and widely disseminated information. Industry groups in competition with PVC generally thought that a ban would be most effective.

• Stakeholders agreed that the tax revenues should be used to mitigate the impacts of the program.

• There is a need to target PVC products with fast turnaround, such as packaging.

• The consultant suggested (2) that the most effective taxes will be on the generation of waste PVC. Voluntary programs for PVC use reduction may have limited effectiveness. Bans based on environmental impact and not economic impact would be most effective.

• Regulatory approaches could consist of a ban on manufacture of PVC, a ban on certain uses (e.g. packaging and other non-durable goods), and prohibition or limits on incineration of PVC.

• Pollution prevention can provide information and moral suasion. This can consist of information on environmental impacts of PVC. It can also provide information on audit programs and alternatives.

CONCLUSIONS

Economic instruments may have only limited applicability to persistent toxic substances. However, they may play a useful role in conjunction with pollution prevention, regulation, and other elements of the virtual elimination strategy. There are, however, a number of information gaps that preclude determination of the “right price” schedule for economic instruments.

Although economic instruments consisting of emissions trading programs may not be appropriate for persistent toxic substances, a trading program that includes staged reduction in emissions toward virtual elimination, may be feasible.

De facto subsidies and avoided-cost benefits may deter changes in production processes, product/material use, and policy that would favour movement toward, and achievement of the virtual elimination goal. A full-cost accounting system may be appropriate for those activities and industrial sectors that contribute persistent toxic substances to the ecosystem. Full-cost accounting should be based on a life cycle approach, by applying taxes to inputs and emissions to all media, and on an incremental basis to complement a sunsetting timetable. In moving toward full-cost accounting, an initial step must include identification of avoided costs as well as direct and indirect subsidies provided to polluters through preferential pricing of energy and resource inputs, tax incentives, limited liability, and external costs (such as damage and cleanup costs) borne by society.

An environmental levy or tax system should be applied at all stages of production, use, and distribution. This would ensure that the environmental consequences of producer and consumer choice are more fully reflected in the price of products, and that polluting activities pay at all levels. This system of levies could be termed an “environmental devaluation tax”, and any new tax changes or increases should include such a component. The revenues generated should be accounted for and applied to protection and remediation efforts, in order to sustain public support. The incentives can work and there is a need to move as soon as possible. Concurrently:

• There is a need to develop an implementation framework, in order that the holistic approach to the tax base be realized and that all persistent toxic substances be treated equitably.

• Further work needs to be done to identify what the “right price” means in terms of encouraging virtual elimination. This includes prevention and remediation costs, and environmental damages. Also needed are targets and timelines to evaluate progress.

• More information is needed on production, use, generation, distribution, releases, and sources, to better target and prioritize the initiative, and to determine the appropriate tax levels and financial incentives for protection and remediation.

• There is a need to focus on prevention at the front end of processes.

• Efforts are needed to extend the prevention and sunset initiatives nationally and globally, for many environmental reasons. As well, from an economic perspective the rationale is the so-called “level playing field.”

Other economic considerations pertain to questions posed by sustainable development and global competitiveness. In many respects, these aspects are closely related. The concept of sustainable development is at once a moral ethic and equally a practical ethic as well. The challenge is not to stop all economic activity or to stop working, but to find a way to live that does not have environmental degradation and destruction as a byproduct. As the Brundtland report (5) and others have pointed out, past development patterns based on expansion of the quantitative
scale of production are the kind that have led us to
the need to eliminate persistent toxic substances, and
are not a sustainable way of life.

Called for are ways of development and doing
business that actually improve our surroundings, so
that further development can take place. This is the
“new kind of growth” called for by Brundtland,
where the environment is an ally, not a victim.
Sustainability means that there is no more important
outcome in our lifetime than the survival of the life-
support systems of the planet. The socio-institutional
climate in the Great Lakes, North America and,
indeed, globally is slowly changing and adapting to
this truth.

Economic survival, at a standard our society and
institutions would know and accept, depends on our
recognizing this ecological reality and the evolving
socio-institutional climate, and matching a new,
sustainable, technological and economic paradigm or
style to it. There is evidence and argument that big
boom periods of real wealth creation occur when a
good match is made. The present point in global
environmental and economic history presents both
the opportunity to take the “good match” branch, and
the danger of trying vainly to continue past trends.

The economies and trading blocs of the world are
in a successional phase which involves a process of
deep structural change. This restructuring is also a
process of “creative destruction,” and provides the
chance to make the “good match.” The critical issue
in this process is that whether the succession is
progressive or retrograde is a matter of choice. We
can progress to a new era of productive capitalism,
where restructuring and wealth creation turn on
restoring and protecting the life support systems of
the earth, or we can regress to Victorian capitalism.

Progressive succession depends on the right
choices. We need to be very careful not to import
into our strategic thinking, too many preconceptions
from economic ages and realities that no longer exist,
and theories that no longer apply. At turning points,
determinism dies, uncertainty reigns, and only wilful
choice, and a charted course, will get us where we
want to go. The phasing out of an inherently danger-
ous and hazardous chemistry based on persistent
toxic substances, and the promotion and further
development of substitutes, would be a progressive
succession based on productive capitalism.

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APPENDIX D

THE INJURY

A Report to the
Virtual Elimination Task Force

DISCLAIMER
The views expressed in this appendix do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission.
INTRODUCTION

This appendix describes the injury to living organisms associated with exposures to persistent toxic substances. Evidence of serious problems provides the catalyst for the development of, and the commitment to implement a strategy to virtually eliminate the inputs of persistent toxic substances into the Great Lakes Basin Ecosystem and, thereby, eliminate the resultant health and environmental effects.

In 1987, the Commission's Great Lakes Water Quality Board reported that 362 chemicals, many human-made, were confirmed to be present in the waters, sediments, and biota of the Great Lakes Basin Ecosystem (152). Moreover, the U.S. Fish and Wildlife Service, in 1977, identified nearly 500 organic compounds in adult lake trout and walleye collected from the Great Lakes. In all, the number of human-made chemicals detected in the basin's environment may be well in excess of 1,000. Chapter 4 describes the criteria used to determine how many of these contaminants meet the definition of a persistent toxic substance. Once a substance is so defined it must be subject to the virtual elimination strategy.

There is general agreement that a number of the contaminant substances routinely found in the basin already meet the definition of a persistent toxic substance. Exposures to these contaminants present a continuing threat to the health of the ecosystem and require a concerted, coordinated effort to eliminate inputs so as to reduce their levels in the lakes. This threat prevails despite substantial reductions in ecosystem concentrations of some persistent toxic substances from the peak levels of the 1960s and 1970s. Presently, in many cases, contaminant levels have not decreased since the 1980s and, in some cases, appear to be increasing (see, for example, Figures E-1 and E-5).

The 11 Critical Pollutants that appear in Table D-1 were identified by the Great Lakes Water Quality Board in 1985, based on their persistence and ability to induce adverse human and numerous environmental health effects (153). More recent information has identified many other compounds of concern, including cadmium, arsenic, alkyl-metals as a class (e.g. tributyl tin), the three hexachlorocyclohexane isomers, chlordane, and heptachlor (44). There are also numerous "lists" of chemicals, perhaps the latest being that associated with the U.S. Environmental Protection Agency's (EPA) Great Lakes Initiative.

Although polychlorinated biphenyls (PCBs) and some chlorinated hydrocarbon pesticides have been subject to bans or use restrictions, these measures are not absolute. Inputs of these persistent toxic substances continue, and they are still pervasive in the Great Lakes ecosystem and its food chain at levels sufficient to cause injury to living organisms.

Exemptions from the PCB manufacturing and import ban were legally petitioned for by about 115 companies, and it is estimated that more than 50% of all the PCBs ever produced are still in use. Loadings of PCBs continue from a variety of sources, some known, and many unknown.

Many chlorinated hydrocarbon pesticide bans or restrictions (e.g. DDT, dieldrin, endrin, aldrin, chlordane, toxaphene, heptachlor, and mirex) apply only to domestic uses, and are not scheduled to come into effect until existing stocks are depleted. Thus, very large quantities of these banned or restricted pesticides are still produced in the United States and exported. As well, commercial products containing many of these pesticides are still for sale in North America. This includes reports that DDT can be purchased despite a 1990 ban on its sale (44-46).

This continued production, sale, and export provides numerous opportunities for releases to the environment and, ultimately, additional inputs to the Great Lakes. Thus, despite the "ban" on DDT by the United States and Canada in 1972, this substance and its metabolites continue to be detected in the tissues of Great Lakes fish, as reported by the Great Lakes Water Quality Board (1), U.S. EPA, and, the Canada Department of Fisheries and Oceans (DFO). The most recently published data for contaminants in fish come from a 1992 Consumer Reports survey (2) which found measurable levels of DDT, along with its metabolites DDD, and DDE. Data on numerous contaminants found in fish are collected by, and are available from the U.S. Fish and Wildlife Service and Canada DFO.

THE WEIGHT OF EVIDENCE

Evidence of the injury caused by persistent anthropogenic toxic substances has been examined and reviewed comprehensively in more than 10 recent reports. The "weight-of-evidence" considered in those reports, and in this appendix, covers a broad range of the types of evidence that are available.
Appendix D

It is beyond the scope of this appendix to describe, for each separate study, possible flaws and strengths in the methodologies, and flaws and weaknesses in the data. That is inherent in the review and case study reports and in other studies as well. Furthermore, a number of these lines of evidence are derived from rigorous application of several criteria and principles for inferring or deducing possible causal relationships -- cause-effect linkages -- between observed injury and the substances thought to be mostly associated with the toxic effect (47). Especially noteworthy in this regard is the special issue of the *Journal of Toxicology and Environmental Health* (Vol. 33, No. 4, 1991, edited by Gilbertson and Schneider); that issue deals solely with the impacts of toxic chemicals on Great Lakes organisms, including humans. It is this thorough, consensual, mutually supporting and rigorous application of the scientific process that allows statements about the weight of evidence to be made in this short appendix on the injury.

Finally, where existing studies are limited, for example, regarding effects on humans, the adage that, “Absence of evidence is not evidence of absence,” should be noted. Complete rational knowledge is not accessible to us and, therefore, judgement is required. Thus, we rely on “weight of evidence.”

Table D-1
Critical Pollutants Identified by the Water Quality Board

- Total polychlorinated biphenyls (PCB)
- DDT and metabolites
- Dieldrin
- Toxaphene
- 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)
- 2,3,7,8-tetrachlorodibenzo furan (2,3,7,8-TCDF)
- Mirex
- Mercury
- Alkylated lead
- Benzo(a)pyrene
- Hexachlorobenzene

(including correlative, statistical, mechanistic, and/or cause-effect linkages), and that are pertinent to the Great Lakes situation. Not only are many individual studies considered but, most importantly, these studies are not considered in isolation. Also included are comprehensive and authoritative reviews and case studies, syntheses, consensus statements, and workshop and symposia reports, wherein the evidence, positive and negative, the data, and the inherent uncertainties, are evaluated, weighed, articulated, and referenced.

Table D-2
Principal Contaminant-Related Effects Observed in Great Lakes Wildlife

<table>
<thead>
<tr>
<th>Species</th>
<th>Population Decrease</th>
<th>Effects on Reproduction</th>
<th>Eggshell Thinning</th>
<th>Congenital Malformations</th>
<th>Behavioural Changes</th>
<th>Biochemical Changes</th>
<th>Mortality</th>
<th>Alterations in Recruitment</th>
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</thead>
<tbody>
<tr>
<td>Mink</td>
<td>X</td>
<td>X</td>
<td>NA</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>X</td>
<td>S</td>
</tr>
<tr>
<td>Otter</td>
<td>X</td>
<td></td>
<td>NA</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Double-crested cormorant</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>S</td>
<td>S</td>
<td>S</td>
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<tr>
<td>Black-crowned night heron</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Bald eagle</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>S</td>
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<td>X</td>
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<td>Snapping turtle</td>
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<td>X</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
</tbody>
</table>

X = effects documented and reported in the published literature. Unpublished records of congenital malformations exist for the double-crested cormorant, the great blue heron, and the Virginia rail.

NA = not applicable
NE = not examined
S = suspected, since population declined

Source: Reference (20).
FISH CONTAMINATION AND WILDLIFE IMPACTS

Fish are excellent indicators of ecosystem health because they are routinely exposed to aquatic contaminants and bioaccumulate and biomagnify many of them — often to many orders of magnitude greater than ambient concentration levels of the surrounding waters. In general, greater concentrations of contaminants are found in predatory fish that are at or near the top of the food chain, fatter species of fish and older fish than in younger, smaller or leaner fish. The game fish most prized in the Great Lakes basin — such as coho salmon, lake trout, and brown trout — have been found to contain the highest levels of synthetic organic contaminants.

The types and levels of chemical contaminants in fish are a reflection of the purity of the waters in which they live and the foods they eat. The fact that any contaminants are present in fish caught in the basin or elsewhere should be viewed as a symptom of a much larger problem of environmental degradation.

There is reason to believe that the adverse reproductive and developmental effects observed in wildlife may foreshadow human population effects. Wildlife may, in fact, be the "canary in the coal mine" warning us of a potential blight on ourselves and future generations yet unborn. Wildlife living in the Great Lakes basin, especially those that feed on fish or fish-eating animals, have shown a wide variety of adverse health effects linked to toxic chemicals. The most insidious and devastating of these effects involve the large number of persistent toxic substances that mimic sex hormones and can disrupt the developmental process in unborn offspring (44,48).

Contaminants are known to cause various problems for animals that have a pathway for increasing exposure (normally those at the top of the food chain). While animals lower in the Great Lakes food webs may not be exhibiting overt signs of toxicity, the compounds mentioned earlier appear responsible for problems observed in the top predators of the Great Lakes ecosystem. This is due to the bioaccumulation and biomagnification of these contaminants in successive organisms along the food chain.

For example, DDT and dioxin-like PCB congeners are implicated in the near extinction of the bald eagle and the brown pelican. Although bald eagle populations have increased along the Great Lakes, shoreline populations are not experiencing as rapid an increase as inland areas (3,28,49). Part of the reason is because elevated levels of a metabolite of DDT (DDE) as well as planar chlorinated hydrocarbons (mainly several PCB congeners) are still found in bald eagles living close to the shore. DDE, PCBs, and dieldrin are present in the eggs of bald eagles feeding on Great Lakes animals. The concentrations found in these eggs are known to reduce hatching success, consistent with observations made by the U.S. Fish and Wildlife Service (4,49,51).

As a result, much of the formerly occupied bald eagle nesting habitat along the shoreline of Lake Ontario has not been inhabited by eagles since their disappearance from these areas in the 1970s (49). Habitat destruction and other stresses have been suggested as possible causes of decline; however, it is reported that many of these stresses have been controlled or reversed. In particular, it is reported that, in New York at least, and possibly for Lake Ontario generally, potential habitat is not lacking (20,49).

Other predatory bird species in the Great Lakes are also experiencing chick death, and deformities such as crossed bills (51-53). This deformity has been noted in Forster's terns (5,50,51) and double-crested cormorants (6,50,51) in Green Bay on Lake Michigan, and the common (7) and Caspian terns (8,50,51) from Saginaw Bay on Lake Huron. While other Great Lakes areas have not been well studied, anecdotal reports suggest that fish and wildlife deformities are being seen at other locations as well (9). This injury continues despite significant recoveries in a number of resistant species, from the reproductive failure of the 1970s.

There is a considerable body of evidence that indicates a causal association between persistent toxic chemical exposures and tumor frequency, deformities, and other lesions in fish — especially bottom feeders (10-16,20,54). Reproductive impairment in lake trout and other fish, including egg and fry mortality, also continues to be observed (12,54-57). A review of findings in the wildlife population literature, presented in Tables D-2 and D-3, found effects involving reproductive behaviour, adverse reproductive outcomes, and neurobehavioural alterations for 14 species of fish, reptiles, birds and mammals living in polluted areas of the Great Lakes basin (17,20,28,47-49,54). The inference of causality implicating persistent toxic substances in these effects continues to gain support due to recent events.

In the two years that followed the 100-year flood event of 1986 in the Saginaw River/Bay ecosystem, the reproduction of Caspian terns collapsed, and then slowly recovered (50). Planar PCBs were implicated as the cause of this reproductive failure and accompanying severe bioeffects (50). Elsewhere, a large colony of ring-billed gulls, on Lake Erie's Maumee Bay, failed to hatch a single egg in 1991 — even though the colony contained 2,000 nests and usually produced 2,500 chicks (19). Inasmuch as the colony is located on an artificial "island" built on dredge spoils from Toledo Harbor, toxic contaminant poisoning is suspected as the cause of this catastrophe. However, confirmatory body burden analysis was not available for this review. This event was coincident with the "wasting syndrome" death of eight of 12
Appendix D

Multimedia analyses in the Great Lakes region indicate that the majority (80-90%) of human exposure to organochlorine compounds such as PCBs and DDT comes from the food pathway, a lesser amount (5-10%) from air, and trace amounts from water. Several investigators (20,30,44,54) have demonstrated that, for fish eaters, human exposures from contaminated fish far outweigh exposures to contaminants through air, water, or soil, although the atmosphere is the dominant medium of transport and deposition to land and water for many persistent toxic substances (136). These patterns of exposure may vary for populations living in the vicinity of industrial activities. As well, high exposure to contaminated fish (and other wildlife) occurs in certain human subpopulations.

One study in Michigan demonstrated that sport anglers who ate Great Lakes fish -- especially trout and salmon -- had higher blood and tissue levels of PCBs than individuals who seldom or never ate such fish (31). The study also showed that fish eaters...
### Table D-3
Cause-Effect Linkages of Persistent Toxic Substances

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Species</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDE, dieldrin, PCB</td>
<td>Bald Eagle</td>
<td>Eggshell thinning; embryo mortality; adult mortality</td>
</tr>
<tr>
<td>PCB</td>
<td>Forster’s tern</td>
<td>Embryonic mortality; deformities</td>
</tr>
<tr>
<td>Dioxin, PCB, DDT</td>
<td>Double-crested cormorant</td>
<td>Embryo deformities; eggshell thinning</td>
</tr>
<tr>
<td>PCB</td>
<td>Snapping turtle</td>
<td>Embryo abnormalities; embryo mortality</td>
</tr>
<tr>
<td>PCB, dioxin</td>
<td>Mink and otter</td>
<td>Reproductive dysfunction</td>
</tr>
<tr>
<td>PAH</td>
<td>Brown bullhead</td>
<td>Liver and skin tumors</td>
</tr>
<tr>
<td>PCB</td>
<td>Lake trout</td>
<td>Unable to reproduce normally; hatchability and fry mortality</td>
</tr>
<tr>
<td>Dioxin, PCB, DDT</td>
<td>Herring gull</td>
<td>Embryonic mortality; porphyria; thyroid hyperplasia; Vitamin A depletion; deformities; feminization; poor parenting</td>
</tr>
<tr>
<td>PCB</td>
<td>Human offspring</td>
<td>Short-term memory deficits (visual, verbal, quantitative, pictorial); growth retardation; activity retardation</td>
</tr>
<tr>
<td>Lead</td>
<td>Human offspring</td>
<td>Hyperactivity; permanently reduced intelligence; neurobehavioural abnormalities</td>
</tr>
<tr>
<td>Mercury</td>
<td>Human offspring</td>
<td>Learning and motor skill deficits</td>
</tr>
</tbody>
</table>

*Sources:* published literature cited in this appendix.

### Table D-4
Disruption to Endocrine Systems in Wildlife

<table>
<thead>
<tr>
<th>Effect</th>
<th>Species</th>
<th>BIRDS</th>
<th>FISH</th>
<th>SHELLFISH</th>
<th>TURTLES</th>
<th>MAMMALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid Dysfunction</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased Fertility</td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased Hatching Success</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>Gross Birth Defects</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metabolic Abnormalities</td>
<td></td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behavioural Abnormalities</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demasculinization / Feminization</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defeminization / Masculinization</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compromised Immune System</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n/a = not applicable

consumed an average of 32 pounds of fish per year and that some ate as much as 262 pounds of fish per year. In another study, the quantity of Great Lakes fish consumed by pregnant women correlated with the levels of PCBs found in their breast milk and tissues, and in their children, when born and later in life (32,33,81-85,156). More generally, for a number of persistent toxic substances, an association has been made between human body burdens and the regular inclusion of fish in the diet (20,44,54,55,76-78).

Taken together, these studies raise concerns for local Great Lakes populations who, because of habit or necessity, consume large amounts of Great Lakes fish and as a consequence may be especially vulnerable to the adverse health effects associated with such dietary exposures (20,34,44,54,76). For example, an April 1993 study published in the Journal of the National Cancer Institute reported a significant and strong association between blood levels of DDT/DDE and breast cancer, and an elevated risk of breast cancer associated with PCBs, although this association was not statistically significant (79). It is significant that this report was the subject of an accompanying editorial (80) and press release from the journal's managing editor, both referring to it as a "wake-up call." See also (158-177).

Infants born to women who consumed two to three Lake Michigan fish meals per month for at least six years preceding their pregnancies had lower birth weights, shorter gestational periods, and smaller head circumferences when compared to infants born to women who had not consumed Lake Michigan fish prior to or during their pregnancies (20,21,36,44,54,81-85). Testing of these infants at seven months of age showed that the infants born to fish-eating mothers had discernible cognitive, motor, and behavioural deficits (36,81-83,85). Altogether, 73 potential confounding variables were screened, and the effects of 37 were able to be assessed. Although the exposed group of mothers had higher alcohol, caffeine, and cold medication use, these confounders were controlled or adjusted for in the statistical analysis. As a result, these variables do not account for any of the observed effects associated with PCB exposure (81-85,156). As well, socio-economic status was not a significant confounder (84,85).

The deficits observed during the postnatal period persisted when these infants were retested at the age of four years (36,81-83,85). The researchers observed that there was a "...reasonably consistent pattern of physical growth and short-term memory deficits that appear to be related specifically to prenatal exposure..."(36).

During administration of the psychological tests at age four, 17 youngsters became intractable and refused to take the tests (36). It was determined later that these children were born to women with the highest levels of PCBs in their breast milk. It is interesting to observe that the behaviour seen in these children parallels the aversive behaviour of rats fed Lake Ontario fish, which was discussed earlier although, strictly speaking, one cannot conclude a cause-effect link based solely on this observation.

This concept of in utero injury to the unborn, due especially to persistent toxic substances that interfere with the extremely subtle and sensitive workings of the endocrine systems, including sex steroid metabolism, is of profound consequence. It is the recently published consensus conclusion of a multidisciplinary group of experts on this issue (noted above) (48) that:

"The concentration of a number of synthetic sex hormone agonists and antagonists measured in the U.S. human population today are well within the range and dosages at which effects are seen in wildlife populations. In fact, experimental results are being seen at the low end of current environmental concentrations."

This is consistent with a 1992 review in the British Medical Journal (158) and a related 1993 study published in The Lancet (86; cited in 87,88) where it is hypothesized that increased fetal exposure to estrogens or estrogenic chemicals (persistent toxic substance endocrine disruptors such as DDT, PCBs, dioxins, furans, hexachlorobenzene, other organochlorine chemicals, and metals) may be responsible for declining sperm counts and a rising incidence of abnormalities in the male reproductive tract (See also 89,99-116,136-139,158-177, and especially 110).

Taken as a whole, the evidence accumulated over the past three decades indicates that exposures to persistent toxic substances are associated with injury, disease, and/or death in a wide-variety of life forms. In aquatic animals and wildlife, the most consistently reported effects include reproductive failure, population declines, developmental abnormalities, and generational effects. Grossly observable effects in these species include adult and embryonic death, teratogenic and neurobehavioural effects, and cancer.

Other adverse health effects have been reported in children born to women who consumed contaminated fish obtained from Lake Michigan. The latest published evidence suggests that persistent toxic substances, particularly organochlorine chemicals, may be important etiologic factors in breast cancer and reproductive disorders in human males. Further evidence, considered below, adds additional weight to these associations with human injury.

The International Joint Commission has concluded (35,155) that the presence of persistent toxic substances in the Great Lakes basin present an ongoing threat to the health of the ecosystem that must be aggressively controlled for the benefit of all.
users of this natural resource. Also, there is increasing advocacy from others to define the problems with consideration to the whole gamut of health effects, especially in utero damage to the unborn, and that these be incorporated into policymaking. The present emphasis on cancer is inadequate (135).

THE INJURY TO THE ECONOMY AND SOCIETY

Persistent toxic substance contamination has also injured the economy and society: real and suspected human injury and health costs; real environmental costs and loss of economic value; and a buildup of costs in the form of an “environmental deficit” -- a debt of problems, cleanup costs, and risks that are shifted to the future, and to society at large. With few exceptions, information is lacking on the direct and indirect economic and societal costs accumulating due to persistent toxic substances. These outstanding and unresolved costs emphasize the need for prevention of persistent toxic substances pollution. The rationale for cleaning up is based on these effects and subsequent “costs.”

Concern about the cause of human disease is particularly relevant because hospital, medical, and prescription drug costs are an enormous individual, social, and economic burden in North America. Human disease is the result of many causes: diet, living habits, stress, as well as chemical exposure. The remediation and prevention of Great Lakes pollution by persistent toxic substances removes a significant and involuntary cause of adverse effects on the health of the population. The potential scope for these associated health costs was reviewed in a report to the Virtual Elimination Task Force (90) and is briefly summarized here.

Many health costs in Ontario and the United States are for the treatment of chronic degenerative diseases (e.g. cancer, circulatory, respiratory, nervous system) (91-94). It is noted that a number of people in Ontario hospitals suffer from neurological disorders; the nervous system most likely is very sensitive to persistent toxic substances (36,44,54,73-75,81-85,149). In Ontario, the cancer wards reflect heavy caseloads, as steadily increasing age-adjusted total cancer rates now imply a population incidence of one in three.

There is evidence that cancer is increasing in some industrial countries at a rate above and beyond what can be attributed to aging and smoking alone (95,96). While carcogenesis is a multi-stage, multifactor disease involving a number of causes including diet, lifestyle, stress, and occupation, persistent toxic substances are still a causal factor. The editors of the Journal of Environmental Carcinogenesis and Ecotoxicology Reviews expressed the view that the increasing incidence of human cancer cannot be separated from the many etiological and contributing factors linked to environmental quality as a whole, including chemical pollution of the biosphere (97).

There is other evidence that exposure to persistent toxic substances, for example, some halogenated hydrocarbons, increases cancer risk (17,98,117-127,158-177). The studies on world sperm counts also observed that while the sperm counts were falling since 1940, the incidence of testicular cancer has risen fourfold in many countries, and that congenital anomalies of development of the reproductive tract in boys have also increased (86-88,110,137-139,158).

One must also note the link recently shown between chlorination byproducts and bladder and rectal cancer (126), in addition to the published reports noted earlier of a putative link between the rising rate of breast cancer in women and the estrogenically active industrial chemicals, particularly the chlorinated hydrocarbons such as DDT and PCBs (44,50,79,131-134).

The tendency or predisposition for some diseases may be passed from parents to offspring (125-127,137-140,142). Other diseases (e.g. cancer, autoimmune, and atherosclerosis) of a chronic nature have a significant somatic, genetic component (17,140-144,158-177). Significant costs are also associated with diseases of the reproductive organs and with a number of problems related to pregnancy and childbirth (91). The U.S. Public Health Service recently concluded that there is an increased risk of birth defects, premature births, and low birth weights associated with chlorination byproducts in drinking water (129, 130).

As discussed above, the persistent toxic substances health threats of most concern in the Great Lakes region are reproductive, intergenerational, genetic, and chronic. From the weight of evidence, it logically follows that there is likely some proportion of these real economic health care costs associated with their production, use, disposal and release into the environment. If these agents are responsible for only 10 to 20% (an “excess” risk beyond the power of most epidemiology to detect) of the disease cost burden, then this amounts to more than $100 to 200 billion/year for the United States and Ontario alone, i.e. about $400 to 800 per capita per year.

Unfortunately, we are simply not in a position to provide the most convincing scientific evidence for showing that persistent toxic substances are injuring humans -- that is, published data derived from human studies with the power to detect the many possible small risks of injuries that can do a lot of damage, and cost society a lot of money and grief because of the large numbers of people exposed (145-149). There are many confounding influences that are difficult, if not impossible to unravel (150,151). In this regard, it is important to note that some of the possible effects are not primarily dose-dependent but depend on...
genetic susceptibility (147-149). There is substantial variance in biological makeup and sensitivity among individuals (48,148).

As a result, when everyone in a population is exposed to the same external toxic agent(s), the distribution of cases, or effects, is determined by individual susceptibility (147). As well, many toxic effects involve the accumulation of subtle and irreversible damage, making it unsure that there are dose levels, however small, that do not produce untoward effects (98,140,146-148). This situation presents the paradox, that the more widespread is a particular toxic substance, the less it explains the distribution of cases or effects, so that real cause-effect relations may be quite unfindable by traditional methods of study, which depend on exposure differences (145,147-151). This situation also characterizes the nature of human exposures to many persistent toxic substances, in complex mixtures, in the Great Lakes basin and elsewhere in North America.

Therefore, the potential for human and economic injury from exposure to persistent toxic substances is, and will likely remain in controversy. Some argue against, and are unwilling to accept even the 10% scenario noted above. Others argue that the cost considerations noted are likely vast underestimates because they are based on today's and yesterday's data, the status quo. These data, it is argued, do not account for the impacts of future long-term chronic conditions with their roots in toxic chemical exposures.

OTHER MEASURABLE ECONOMIC COSTS

The most obvious and measurable costs stem from damage to fish and wildlife. Often, the losses are to subsistence hunters and fishers. These costs can seem relatively small, in part because the marketplace places such a low monetary value on them, and in part because few human and capital services are required in their production. Therefore, economic costs or losses related to fish and wildlife should not be used as, or confused with their real systemic value as an integral part of the web of life. It does not do justice to native North Americans who have lost a way of life, linked with fish and wildlife, to assign a dollar value.

The loss of commercial fisheries represents one of the first and most easily identifiable losses of economic value. Lost income estimates, in 1990 dollars, due to persistent toxic substance-related closures or market losses include: mercury in Lake St. Clair at about $5 million/year; mirex in Lake Ontario at about $2 million/year; and persistent toxic substances in Lake Ontario carp and mirex in sport fish caught for sale at about $1.5 million/year.

The loss to subsistence fishers has not been estimated; however, the total food value of the Great Lakes fishery was estimated at $270 million in 1986. This is an equivalent capital value of $2.7 billion in perpetual bonds at 10%. For a Great Lakes basin population of 36 million, this amounts to $75 per capita. Losses due to injury to other wildlife of food value are unknown.

Risks to health also lie behind the debate over improved drinking water treatment to remove toxic substances (39,157). The recent evidence, cited above, on the risks of chlorination byproducts in drinking water provides a further basis for the debate. In 1986, it was estimated to cost about $171 million/year (CAD) for the installation of granular activated carbon treatment systems on all Canadian drinking water treatment plants using the Great Lakes as source (37). In 1990, the same cost for Toronto alone was estimated at about $80 million/year (39). It may not be possible, at any cost, to restore major contaminated drinking water supplies, or to reverse environmental destruction.

The social cost legacy of the “environmental deficit” promises to be staggering (40). The costs of containment operation and maintenance, monitoring, and cleanup of leaks from toxic waste sites in the Great Lakes basin is unknown. However, for just the four largest sites along the Niagara River, such costs, based on standard practices, are estimated to cumulate to $6 billion (US) over the next 30 years, and to $19 billion over the next 100 years (37). Based on the current basin population, this is $167 and $528 per capita per year.

Expenditures by governments to clean up around Love Canal are more than $125 million. The so-called “toxic blob” in the St. Clair River has cost the public millions of dollars in studies alone.

The cost of cleaning up the Great Lakes Areas of Concern are beginning to be reckoned. The Northeast-Midwest Institute provided an “initial estimate” of at least $2.9 to $3.4 billion to remediate just 10 of the 43 Areas of Concern (41). This is $80 to $94 per capita. The Great Lakes cleanup is one facet of the huge bill that is coming in, due to past production, use and disposal of persistent toxic substances. According to Great Lakes United in 1986, the eight Great Lakes states contained 327 of the 857 sites on, or proposed for inclusion on U.S. EPA’s Superfund National Priority List. Cost data on these specific sites are not available; therefore, the United States’s national program costs are relevant and informative.

Estimates of remediation costs for the Superfund program in the United States range from $50 to 100 billion or more, with the states (one estimate at $45 billion) and industry needing to spend about twice that much. Remediation work costs at U.S. Department of Energy sites keep being revised upwards to more than $125 billion over the next 20 years. U.S. Defense Department and Resource Conservation and
Recovery Act (RCRA) site cleanups have been put at about $40 billion (42). Based on a United States population of 250 million, this cumulative total amounts to $1,260 to $1,860 per capita. It is not difficult to conceive of a bill surpassing $1 trillion. Indeed, the latest published estimates to remediate the hazardous waste legacy in the United States are in the range of $480 to $1,000 billion, with $750 billion the most likely (43).

Other social and economic costs have not been quantified but should be considered: expenditures of money and personal resources by various levels of government, other agencies, and industry on monitoring and research; lost land value of contaminated waste sites; depressed property values in neighbourhoods around contaminated sites, ecosystems, and industries; litigation costs, and problems of legal liability for contaminated lands; investments in sectors impacted by contamination; lost quality of life in contaminated areas; and loss of competitive advantage.

CONCLUSION

As discussed in this appendix, a substantial body of evidence is now available to document the effects of persistent toxic substances on a wide variety of aquatic biota, birds, and mammals. Of particular concern are subtle, chronic effects of chemical exposures expressed at the level of the hormonal homeostatic systems of many animals studied — often observed as generational and multigenerational insults and injuries. The weight of the evidence reinforces and strengthens the Agreement requirement to virtually eliminate the input of persistent toxic substances into the Great Lakes Basin Ecosystem, and thereby enhance and restore the health and vitality of this precious resource.

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biphenyls produce regional alterations of dopam-


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APPENDIX E

PROGRESS TO DATE

A Report to the
Virtual Elimination Task Force

DISCLAIMER
The views expressed in this appendix do not necessarily represent those of the Virtual Elimination Task Force or the International Joint Commission.
Our understanding of the necessary elements and criteria for a healthy Great Lakes ecosystem has changed over the past decades. In the 1960s and early 1970s the focus was on the reduction of oxygen demand, sedimentation, and eutrophication. In the 1970s the threat from compounds and metals such as PCBs, DDT, mirex, dioxins, furans, mercury and lead became apparent. This has led to control measures and the development of policy statements aimed at the reduction and elimination of persistent toxic substances.

Several measures taken during the past 20 or so years have improved the health of the Great Lakes ecosystem. They include the construction of municipal and industrial wastewater treatment systems, remedial efforts to mitigate contaminants entering or present in the system, process and technology changes made by some manufacturers as well as at least partial restrictions, phaseouts or bans on certain toxic pollutants. Some of these efforts have come as a result of formal policy (legislative/regulatory) initiatives, some were done on a voluntary basis while others have come as companion or offshoot benefits of more traditional pollution control efforts.

Much remains to be done, since injury still occurs to living organisms. However, the increases in bird populations, reductions in bird malformities, and reduction of fish tissue contamination that have been observed in recent years within the basin demonstrate that application of the elements contained within the virtual elimination strategy can lead us to our goal.

EXAM PLES OF MEASURES TAKEN

The discussions which follow serve as examples and describe the implementation of several pollution prevention/pollution control measures which have provided for, or contributed to, ecosystem improvements. These examples include:

- The phaseout of mercury used in chlor-alkali manufacture.
- The phaseout of polychlorinated biphenyl use in electrical equipment.
- Discontinued use of persistent pesticides.
- The phaseout of the use of lead in gasoline.
- The reduction of dioxin discharges from bleached pulp mill effluents.
- Recent regulatory initiatives.

MERCURY USE IN CHLOR-ALKALI MANUFACTURE

In the early 1970s it was found that mercury in the sediments of rivers and lakes was altered by bacteria to methylmercury. Methylmercury is rapidly absorbed by fish either directly from water passing over the gills or ingested with the organisms which serve as food. Since fish eliminate mercury at a very slow rate — much slower than humans — concentrations in fish gradually accumulate. In humans, long-term exposure to mercury can cause neurological damage, kidney damage, severe weight loss, and damage to the fetus.

The mercury cell process for the manufacture of chlorine and caustic soda was found to be a significant source of discharge of this persistent toxic substance to the environment. In response, manufacturers converted operations to an alternate technology (the diaphragm cell process), or installed end-of-pipe technology, in the late 1960s and early 1970s and substantially reduced the mercury discharged from these industrial sources. Since 1978, 16 production facilities in Canada have either been shut down or converted to an alternate technology (1). Similar conversions took place in the United States during the same time. As indicated by the trend line in Figure E-1, the average mercury concentration in walleye in Lake St. Clair declined rapidly during the early 1970s. After reaching a plateau in the late 1970s, concentrations declined further during the 1980s, levelling off at approximately a quarter of the 1970 value.

POLYCHLORINATED BIPHENYL USE IN ELECTRICAL EQUIPMENT

Polychlorinated biphenyls (PCBs) are a group of chlorinated organic compounds first commercially developed in the late 1920s. PCBs are very persistent in the natural environment. They bioaccumulate readily in the aquatic ecosystem. As a result top predator fish species with high fat content (e.g. salmon and trout) have accumulated PCBs to unacceptable levels. In response, PCBs were banned in all new products and are now used only as an insulating fluid in existing closed electrical power transformers and small capacitors. These measures and strict regulations governing the storage and disposal of PCBs and PCB-contaminated equipment have significantly reduced the releases of PCBs into the environment.
and have resulted in declining levels of PCBs in the aquatic environment.

In Lake Ontario, PCBs and mirex are the two contaminants which have been responsible for the majority of the consumption restrictions among fish species with high fat content (e.g. salmon and trout). However, PCB levels have declined to the point that mirex is now responsible for the greater number of consumption restrictions.

Figure E-2 shows the declines in the mean annual PCB levels for boneless, dorsal fillets of coho salmon taken at the Credit River. This species has been tested since 1972. PCB levels have declined such that all coho salmon sampled at the Credit River in 1989 were below the 2.0 mg/kg (ppm) Canadian federal guideline for unrestricted consumption. The Ganaraska River is another popular angling location on Lake Ontario. Rainbow trout have been monitored since 1976. Figure E-3 shows a similar decline in PCB levels in rainbow trout at this location. All rainbow trout were below the 2.0 ppm federal guideline. Figure E-4 shows the decline in PCB levels in lake trout from Peninsula Harbour in Lake Superior. All the lake trout samples from this location are now well below the federal guideline.

DISCONTINUED USE OF PERSISTENT PESTICIDES

Pesticide formulations in the United States and Canada have been modified over the last 25 years. They have changed from toxic, persistent and non-specific organochlorine pesticides such as DDT to the less persistent, but still highly toxic and non-specific organophosphate and carbamate types to lower toxicity, non-persistent and target-specific biorational pesticides and, finally, to biological controls. This evolution has occurred primarily for two reasons:

- Government regulation responding to the problems caused by the toxic, persistent and non-specific organochlorine pesticides.
- The ineffectiveness of older pesticides due to the development of resistance by the target pests.

Pesticide (primarily insecticide) use has been reduced in recent years by use of integrated pest management techniques, which seek to use non-chemical controls whenever possible. However, there has been a major increase during this period in the use of herbicides both for agricultural uses and lawn care.

On the whole, these actions have resulted in a reduction of the quantity of pesticides that ultimately enter the waters of the Great Lakes but not necessarily a continued reduction of concentrations in fish (see, for example, Figure E-5).

LEAD IN GASOLINE

The substitution of lead in gasoline with "unleaded gasoline" demonstrates the principle of phased product substitution as an implementation measure for virtually eliminating a particular use of a persistent toxic substance.

For more than half of the 20th century, from its discovery in the early 1920s, tetraethyl lead was used in gasoline as an octane enhancer. No other single additive produced as large a benefit in fuel efficiency and smooth operation for gasoline-fuelled internal combustion engines. However, in the 1970s, North American auto manufacturers introduced the catalytic converter to reduce emissions of unburned hydrocarbons and carbon monoxide. To prevent "poisoning" of these converters by lead emissions, the petroleum refiners then began to produce "unleaded" or "no lead" gasoline. The volume of unleaded gasoline produced grew steadily through the 1970s and 1980s as more converter-equipped cars reached the market.

In the mid 1970s, a growing concern over health effects associated with the additive caused governments in both Canada and the United States to require a continuing phased reduction. According to Environment Canada (2), there was "... growing scientific evidence that blood lead levels in the 10-25 g/dL range may be linked to various undesirable biochemical neurobehavioural and other subtle subclinical effects." This emerging evidence in the mid- to late-1980s convinced the Canadian government that the negative health effects of lead far outweighed its advantages as a gasoline additive. Use of lead in Canadian motor gasoline was prohibited as of December 1, 1990. The petroleum industry's shift to unleaded gasoline therefore evolved from its modest introduction in the mid-1970s, to 100% no-lead by 1990. This required a major effort to adopt more octane-intensive processing steps within the refineries.

As shown in Figure E-6, the overall result in Canada of this lead phaseout has meant that the concentration of particulate lead in the atmosphere has dropped by 96% between 1973, the year when lead emissions from gasoline peaked, and 1990 (1,3). Figure 3 depicts changes in lead emissions to the atmosphere. Corresponding declines were seen in the average blood lead levels in children within selected urban areas in southern Ontario. These levels are now below those at which deleterious effects have been observed in some population groups. Other studies (1) suggest that a threshold level for lead does not exist. Clearly, the reductions noted have been desirable.
Appendix E

Figure E-1
Average Mercury Concentrations in Walleye Collected from Lake St. Clair, 1970-89

Source: Reference (1). Based on data from the Ontario Ministry of the Environment.

Figure E-2
Mean Concentration of PCB in Coho Salmon Collected at the Credit River

Figure E-3
Mean Concentration of PCB in Rainbow Trout Collected at the Ganaraska River

Figure E-4
Mean Concentration of PCB in Lake Trout from Lake Superior at Peninsula Harbour

Source: Reference (5).

Figures E-2, E-3, and E-4
Appendix E

Figure E-5
DDT in Lake Ontario Rainbow Smelt (Whole Fish)

Source: Reference (4).

Figure E-6
Lead Levels in Air, Canadian Data

Source: Reference (3).
Appendix E

DIOXINS IN BLEACHED PULP MILL EFFLUENTS

In 1986, it was discovered that low concentrations of chlorinated dioxins could be found in effluent streams from bleached kraft pulp mills. These materials were produced as unintentional byproducts of the chlorine-based bleaching processes, which had been in use by the industry for at least 40 years.

Research showed that the relative concentrations of chlorine and lignin materials present in the unbleached pulp, and the sequence of chemical reactions which take place during the bleaching process, produced the unexpected and unwanted materials. Also, it was found that certain oil-based defoamers used at some mills contained precursors which could lead to the formation of dioxins.

As studies continued, the industry learned that process changes could reduce the dioxin content of mill effluent to less than measurable levels. These changes were:

- Substitution of a substantial portion of the chlorine used for bleaching (60% or more) with chlorine dioxide.
- Changing the sequence in which the remaining chlorine is added to the pulp.
- The use of additional chemicals such as oxygen and hydrogen peroxide in some of the process steps.
- The use of chemical or process changes to lower the lignin content of the unbleached pulp prior to bleaching.
- Suspending the use of the oil-based defoamers of concern.

Depending on individual mill configuration, wood species used and final product specifications, a combination of some or all of these process modifications will produce significant reduction of dioxins from these sources. Current data from a United States study (the "1992 Dioxin Profile") confirms that effluents from mills making these changes do not contain detectable quantities of dioxins (6). Studies at a North Carolina mill have shown that high-level chlorine dioxide substitution, has resulted in reductions of an order of magnitude or more in the dioxin concentration in fish flesh.

RECENT REGULATORY INITIATIVES

Several recent policy setting (legislative/regulatory) initiatives targeted for control of toxic pollutants (including persistent toxic substances) have been put in place or proposed in both the United States and Canada. They have given, or have the potential to give, the Parties important tools with which to work towards implementation of the virtual elimination strategy. Some of these initiatives are discussed in detail in Chapter 6; therefore, no analysis is presented here. The important point, with respect to the discussion in this appendix, is that the need for these programs has been recognized. In this way, these programs serve an important function and provide an ecosystem benefit for the basin. As the policy-setting process regarding persistent toxics substances goes forward in Canada and the United States, the decision makers have the following list of programs or proposals (among others) from which to depart.

Canadian Programs

- The (federal) Accelerated Reduction and Elimination of Toxics (ARET) program.
- The Ontario Municipal-Industrial Strategy for Abatement (MISA).
- The Ontario Candidate Substances List for Bans or Phase-Outs.
- The Ontario Draft Pulp and Paper Effluents Regulation.

United States Programs

- The (federal) Great Lakes Water Quality Initiative (GLI).
- The (federal) Great Lakes Toxics Use Reduction (GLTURI) proposal.
- The U.S. Environmental Protection Agency's Pollution Prevention (33/50) Program.
- The U.S. Clean Air Act Amendments of 1990.

Joint Programs

- The Remedial Action Plan (RAP) Program.
- The Lakewide Management Plan (LaMP) Program.
- The Binational Lake Superior Zero Discharge/Zero Emission program.

Industry Initiated Programs

- The Chemical Manufacturers' Association (CMA) and Canadian Chemical Producers Association (CCPA) Responsible Care® Program.
REFERENCES


3. T. Furmanczyk, Environment Canada, personal communication.


