1993-95 PRIORITIES AND PROGRESS UNDER THE GREAT LAKES WATER QUALITY AGREEMENT

Chapter One: Great Lakes Water Quality Board

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1.0 Great Lakes Water Quality Board Activities

Introduction

The Water Quality Board, as a participant in the development and execution of the 1993-95 Great Lakes Priorities of the International Joint Commission, had direct involvement in the pollution prevention, pulp and paper, groundwater and pesticides issues described in this chapter. In addition, the Board provided the Canadian Co-Chair for the Lake Erie Task Force as well as a representative to the Indicators for Evaluation Task Force and to the Annex 2 (RAPs/LaMPs) Steering Committee.

Assigned Board members also provided substantive comment on the Decisionmaking with Limited Information and the Parties Toxic Reduction Program priorities under a Science Advisory Board lead.

What follows is an overview of the four priorities in which the Board had a leadership role: 1) pollution prevention; 2) pulp and paper; 3) pesticides; and 4) groundwater.

1.1 Pollution Prevention: Current Status and Continuing Challenges

1.1.1 Introduction

Virtually every agency in the basin recognizes that a shift in emphasis to pollution prevention has been, and continues to be, appropriate for the achievement of the goal of virtual elimination of persistent toxic substances in the Great Lakes Water Quality Agreement. While there are several definitions of this term, pollution prevention commonly refers to an active application of processes, practices, materials and energy uses that avoid or minimize the creation of pollutants and wastes.

The Water Quality Board and Science Advisory Board of the International Joint Commission, under the 1993-95 Priorities of the Commission, hosted a workshop to review the fundamental issues associated with pollution prevention. Current legislative initiatives, associated programs and projects, emerging considerations and longer-term challenges associated with technology, social and cultural aspects and research and development efforts were all considered. The workshop was held at Ann Arbor, Michigan on March 29 and 30, 1995. This chapter is a report on that workshop augmented by an introductory discussion of the history and evolution of pollution prevention.

Pollution prevention is a mark of the maturation of environmental stewardship. It is frequently viewed as a point of departure from the regulatory control approach of the late 1960s and 1970s, which was most frequently reactive in nature and premised on the deployment of "end-of pipe" control and related removal technology.

One of the first significant corporate pollution prevention initiatives was undertaken by the 3M Corporation in 1975. Operating under the title "Pollution Prevention Pays Program," the initiative had four major thrusts: i) product reformulation; ii) process modification; iii) equipment redesign; and iv) recovery and re-use of waste materials. Within three years, the company estimated that the program had delivered savings of $17 million from their U.S. operations (Thomas Zosel, workshop).

Similarly, in 1973, Union Carbide's Surplus Products Group, which markets process byproducts and wastes, realized $1.2 million in combined income and savings. At approximately the same time, Dow Canada and Diversey Canada transformed waste powder from steel-making into a valuable end product that diverted 4.5 million kilograms (10 million pounds) from landfills to usable applications (Pollution Probe, 1982).

The promulgation of the 1984 Hazardous and Solid Waste Amendments to the U.S. **Resource Conservation and Recovery Act** (RCRA) was a major legislative milestone. These amendments directed the U.S. **Environmental Protection Agency** (EPA) to develop mandatory requirements for the adoption of pollution prevention techniques. In the late 1980s, the U.S. Congressional **Office of Technology Assessment** (OTA) illustrated the need for such an altered approach, noting that "although there are many environmental and economic benefits to waste reduction, over 99 percent of federal and state environmental spending is devoted to controlling pollution after waste is generated. Less than one percent is spent to reduce the generation of waste." The U.S. Pollution Prevention Act of 1990 evolved from this RCRA amendment and the Congressional OTA comment.

The lineage of pollution prevention in Canada is evident in the Federal Environmental Contaminants Act of 1974. The intent of that Act was to move through pollution control to prevention. The enactment of the Arctic Waters Pollution Prevention Act in the same period and a move to outright bans in the use of specific substances or prohibition of particular activities are other aspects of federal government actions that reflect a preventive approach (Verstey 1993).

Developments in Canada culminated in the call for a national commitment to pollution prevention by the Canadian Council of Ministers of the Environment (CCME) in November of 1993. The highlight box illustrates typical actions taken by existing facilities in implementing a pollution prevention approach.

Typical actions selected by existing facilities in implementing a pollution prevention approach include:

- improving housekeeping and performing preventive maintenance to minimize inadvertent spills and releases
- altering production processes or parameters; e.g. reducing operating pressures to reduce fugitive emissions of volatile toxic materials
- extended use, reuse, and recycling within a process; e.g. more effective capture and return of metals from rinse tanks to plating tanks in electroplating operations
- reformulation or redesign of products; e.g. reformulated gasoline to reduce volatile organic emissions into the air
- substitute non-toxic or less toxic substances in the process; e.g. the move from solvent based coatings to water-based coatings
- eliminating the use of specific targeted substances

[Final report of the Pollution Prevention Legislative Task Force. Environment Canada, September 1993]

Following release of the International Joint Commission's Report of the Virtual Elimination Task Force and the Seventh Biennial Report, under the Commission's Priorities for the 1993-1995 Biennial Cycle, the Commission's Water Quality Board was charged to develop an overview of the application and effectiveness of national, state, provincial and other pollution prevention programs in the reduction and elimination of the discharge of persistent toxic substances in the basin called for in the **Great Lakes Water Quality Agreement** (GLWQA).

In response, the Board supported a selected overview of pollution prevention programs and initiatives by the various governments affecting the release of persistent toxic chemicals into the Great Lakes basin.

During the setting of these priorities, the Workgroup on Emerging Issues of the Science Advisory Board was asked to assess the role of technology in achieving the goals of the GLWQA. Subsequently, both Boards cooperated in sponsoring a Pollution Prevention Workshop; deliberations of that workshop make up much of this chapter.

1.1.2 The Legislative Evolution of Pollution Prevention

The U.S. Pollution Prevention Act of 1990

Following the publication of a draft Pollution Prevention policy by the U.S. EPA in 1989, the U.S. Congress declared in 1990 that "pollution should be prevented or reduced at the source whenever feasible." The Pollution Prevention Act has elements that are near universal throughout the U.S. and Canada, namely a call for: i) standard methods of measurement; ii) identification of measurable goals; iii) improved methods of coordinating, streamlining and assuring public access to data collected under federal activities; iv) performance of outreach and facilitation of the adoption of source reduction techniques by the private sector through various support mechanisms, including technical assistance (guidance documents, workshops and other training devices), information clearinghouses, and grant programs; v) identification of incentives and elimination of barriers to source reduction; and vi) establishment of award programs. The language of pollution prevention was subsequently reflected in the reauthorized U.S. Clean Air Act of 1990.

The Pollution Prevention Act, recognizing the existence of a strong regulatory underpinning of effluent control regulations, establishes a four-tiered hierarchy to achieve environmental protection, with the first or most preferred option being source reduction of pollution, followed in descending order of preference by waste recycling, waste treatment and waste disposal as the least desirable option. The federal program under the Act was based on a high level of interaction and cooperation with the states.

Toward the latter part of 1993, the U.S. **General Accounting Office** (GAO) reviewed the implementation of the Pollution Prevention Act. They considered a total of 105 state pollution prevention programs across the U.S. Approximately 20% of the programs were regulatory; 80% were voluntary. The GAO concluded that many state programs did not appear to adequately stress the first option (source reduction) and were inordinately involved in waste recycling, treatment and/or disposal, an approach apparently inconsistent with the policy established by the Act. The GAO also found that, rather than becoming self-sustaining, as called for in the Act, many of these state programs continued to be dependent on EPA funding.

At this initial stage in their deployment, very few of the U.S. pollution prevention programs (federal and state) have established specific reporting and evaluation systems that quantify reductions. Many appear to rely on the **Toxic Release Inventory** (TRI) to provide quantified measures of effectiveness. This U.S. General Accounting Office report, and earlier GAO reports, identified major concerns regarding the use of the TRI, a database not specifically designed for this purpose, to monitor the effectiveness of pollution reduction programs. State managers have encountered several of these difficulties and most have not yet found entirely acceptable alternatives. The question of appropriate quantified measurement will be considered in more detail later.

The GAO report identified specific difficulties with measuring the effectiveness of state programs, singly and on a comparative basis. No common standards of effectiveness exist and most state monitoring systems focus on program efficiency and delivery (ie. number of seminars held, number of plans implemented, etc.) rather than on measuring the reduction of discharges or releases of particular toxic contaminants. Current data on program operations and results were thus unsuitable for aggregation. The data also do not allow determination of the effectiveness of individual programs at the state level. Several causes were identified for these data difficulties: faulty program objectives, often aimed at waste treatment rather than reduction; lack of training in evaluation skills; difficulty in imposing rigorous reporting on voluntary programs; and structural weaknesses in the Toxic Release Inventory database as previously mentioned. A review of information collected on Canadian programs suggests that a majority of these concerns are evident there as well.

Since the completion of the GAO Study, the U.S. federal government has launched the Common Sense Initiative, designed to create and engage multistakeholder teams to focus on the six industrial sectors (automotive, computers and electronics, iron and steel, metal plating and finishing, petroleum refining and printing) that collectively employ four million people, comprise 11% of the Gross National Product, spend more than eight billion dollars on compliance with environmental law and released 180 million kilograms (395 million pounds) of toxic pollutants into the environment in 1992.

In developing strategies for further reduction and elimination of toxic pollution from these sources, the multistakeholder teams, which include local, state and federal government officials along with corporate executives and local and national environmental interest groups, will focus on regulation review, reporting requirements, compliance, permit review, and environmental technology, all in a context of pollution prevention. Pollution prevention will be actively promoted as a standard business practice and a central ethic of environmental protection (Michelle Jordan, workshop).

Canada - Federal and Selected Provincial Initiatives

In keeping with the political structure of Canada, the federal strategic pollution prevention program is being developed in close cooperation with the provinces. In November 1993, the Canadian Council of Ministers of the Environment announced "A National Commitment to Pollution Prevention." In the Ontario region, working closely with the province, the focus has been on forming linkages to the automobile parts manufacturers association, motor vehicle manufacturers association, printing and graphics arts associations, metal finishers and electroplaters. Smaller facilities, such as dry cleaning establishments and individual municipalities, are also actively participating in the program.

A key Province of Ontario initiative is the **Pollution Prevention Pledge Program** (P4). Under this program, initiated in September 1993, facilities *voluntarily* agree to control their emissions to the environment to a level below that required under existing regulations. Facilities are invite to develop their own pollution reduction goals and involve themselves at some level in a four-tiered structure: i) registration and planning; ii) reduction commitment or pledge; iii) reduction achievement; and iv) pollution prevention achievement. The overarching challenge is to reduce the release of some of the persistent toxic and bioaccumulative chemicals by 50% by 1995 and by 90% by the year 2000, based on 1990 levels. A complete description and workbook is available and, by and large, the process is a public one. The first comprehensive report on the P4 initiative should be available toward the latter part of 1995. A few selected programs are described further in the following pages.

1.1.3 Pollution Prevention and the Great Lakes - the Ann Arbor Workshop

As mentioned earlier, the Water Quality Board and the Science Advisory Board convened a workshop on Pollution Prevention at Ann Arbor, Michigan on March 29 and 30, 1995 as part of their exploration of toxic reduction programs and pollution prevention. What follows is a brief synopsis of that workshop.

Pollution Prevention and the Great Lakes Water Quality Agreement

As a region with one of the most developed economic infrastructures in North America, the Great Lakes basin is home to major agricultural, industrial, transportation, energy, consumer, government, recreation and resource extraction sectors. Many of the associated facilities, in resource extraction and processing, and manufacturing in particular, would be considered mature. As a result, while there are significant opportunities to apply fundamental pollution prevention techniques at the process design stage for new or radically altered facilities, other less elemental techniques such as intermediate material substitution and improved containment (including closed cycle operation), are often more amenable to immediate implementation in several sectors.

The Great Lakes Water Quality Agreement of 1978, between the United States and Canada, called upon these nations and associated states and provinces to "institute programs for the abatement, control and *prevention* [emphasis added] of pollution from municipal and industrial sources." Control of pollution from onshore and offshore facilities was also to include programs and compatible regulations for the *prevention* of discharges of harmful quantities of oil and hazardous polluting substances. With reference to shipping sources, the prevention of pollution from the loading, unloading, or onboard transfer of cargo was also advocated. These references were retained in the Protocol to the Agreement developed by the United States and Canada in 1987.

In its role of assessing the implementation of the Agreement, the International Joint Commission, over the past several years, has emphasized the elimination of discharges of persistent toxic bioaccumulating substances in the basin. In April 1990 it established the Virtual Elimination Task Force to develop a strategy to achieve this goal. In it report, that Task Force (p. 44) expressed the concern that "the vast majority of laws in the Great Lakes still retain the pollution control approach that assumes there is an acceptable level of inputs of all chemicals. The governments' "pollution prevention" approach generally pertains to *control* (rather than prevention), focuses on releases (rather than uses) and attempts to determine *acceptable* levels (rather than elimination requirements)."

In their deliberations, the Task Force noted that "prevention attempts to avoid use or generation in the first place, through process change, product reformulation, and raw material substitution ... The goal is clean production processes, closed loop recycling and elimination of the use and generation of persistent toxic substances." The Commission itself, in its Seventh Biennial Report, endorsed the Virtual Elimination Strategy and its call for prevention of such discharges.

One of the first issues the WQB/SAB Workshop Steering Committee faced was that of defining the term "pollution prevention." Under the Pollution Prevention Act of 1990, the EPA has defined pollution prevention as "the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or waste at the source." Included are practices that reduce the use of hazardous materials, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use. Unlike definitions of "waste reduction," off-site recycling activities nor "any practice which alters the physical, chemical or biological characteristics or the volume of a hazardous substance, pollutant or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or the providing of a service" are not included.

The U.S. federal legislation is focused on ***source reduction***, while many of the state legislative initiatives promote ***toxics use reduction***. While this latter focus is seen by some as a more thorough approach to eliminating the presence of a particular contaminant from the ecosystem, others note that it can be considered a limited approach which is often confined to particular listed toxic chemicals and, frequently, specified manufacturing processes.

Under its Pollution Prevention program, the Ontario Ministry of the Environment and Energy states that pollution prevention is "any action that reduces or eliminates the creation of pollutants." It is achieved through activities that promote, encourage or require changes in the basic operational or behavioral patterns of industrial/commercial/institutional or individual generators. It does not include substitution of one toxic substance for another, treatment, out-of-process recycling or incineration or transfer from one medium to another. It is achieved by raw material substitution, production reformulation, process redesign or modification, in-process recycling or improved maintenance and operation.

A review for Environment Canada examined 23 state laws and isolated no fewer than 10 discreet terms claiming to be synonymous with pollution prevention, including hazardous waste reduction, waste reduction, source reduction, waste minimalization, toxics use reduction, toxic pollution prevention and pollution prevention.

Pollution prevention is seen by many as a broad concept, built on the foundation of waste reduction and waste minimization, augmented through the inclusion of products as well as processes. Dr. Larry Ross of the American Institute of Chemical Engineers Centre for Waste Reduction Technologies has suggested the following "ideal" definition of pollution prevention as "activities that have the potential to transform industry from material intensive, high throughput processes to systems that use fuel and raw materials highly efficiently, rely on inputs with low environmental costs, generate little or no waste, recycle residuals, and release only benign effluents."

1.1.4 Basin Program Overview

While this report is not meant to provide a detailed account of pollution prevention programs in the basin, a few will be briefly noted to give a sense of the industries involved, the approach taken, and the results achieved.

Initiatives in the automobile manufacturing industry, both by primary producers and by their suppliers, are indicative of industrial activities on both sides of the Great Lakes basin boundary. In the American portion, a voluntary program was initiated in 1991 by the American Automotive Manufacturers Association and the Michigan Office of Waste Reduction Services, managing the project on behalf of the eight Great Lakes States and the federal government.

By early 1994, 16 individual projects under this program had achieved a 20% reduction in persistent toxic releases to the Great Lakes and a 28.9% decrease in the release of toxic substances by the manufacturers to less than a kilogram (2.2 pounds) released for every car manufactured (Automotive Pollution Prevention Project: Progress Report 1994).

Similarly, in Canada, the Motor Vehicle Manufacturer's Association, in conjunction with Environment Canada and the Ontario Ministry of Environment and Energy, has launched several initiatives. One, the elimination of methylene chloride in paint strippers, has resulted in a 37% saving in costs and the elimination of 63,000 litres (17,000 gallons) per year of methylene chloride; this was accomplished with no significant capital investment. Since the initiation of the program, estimated releases of toxic substances have been reduced by 2 million kilograms (Ron Shimizu, workshop).

The focus of efforts in this area has now been broadened to the metal finishing and other auto parts manufacturing facilities. Significant reductions are being achieved in both.

Binational Program: Lake Superior

In response to the Commission's challenge in 1989 to use Lake Superior as a zero discharge demonstration area, the Canadian and the U.S. Federal Governments have linked with Michigan, Minnesota, Wisconsin and Ontario to develop the Lake Superior Binational Program. Pollution prevention is an integral part of the program; specific initiatives include development of a coordinated pollution prevention strategy among the U.S. EPA and three Lake Superior states (Minnesota, Michigan and Wisconsin). The pulp and paper industry has been a particular focus of this effort, with the development and demonstration, supported by the Canadian and Ontario governments, of a pilot chlorine-free bleach kraft pulp process at Red Rock, Ontario.

Numerous linkages have also been forged at the local level, particularly through direct technical assistance to improve operation of wastewater facilities through renewed pretreatment efforts to limit or eliminate toxic inputs to facilities. Similar pretreatment strategies have also involved hazardous waste collection activities and the development of community plans to further prevent and reduce pollution.

The European Experience

Several multi-lateral agencies, including the **Organization for Economic Co-operation and Development** (OECD), the United Nations Environmental Programme and the United Nations Industrial Development Office, have addressed pollution prevention either directly or through green technologies or sustainable development considerations.

The **North Atlantic Treaty Organization** (NATO) has sponsored a study called "Pollution Prevention Strategies for Sustainable Development" involving 14 countries in an information exchange program on pollution prevention policy, education and technology.

A major thrust in Europe is 'clean production,' which is seen as a necessary precedent to clean recycling. This approach is reflected even at individual residences; in Holland it is now compulsory for all households to sort food waste to allow intensive composting. Denmark considers the operation of energy-from-waste facilities, fuelled in part by carefully sorted household refuse as a significant component of its pollution prevention strategy (Hans H. Christensen, workshop).

In 1990, as a result of an extensive lifecycle analysis, the Swedish Government moved to a strategy of banning or phasing out hazardous products. Among the first products reviewed for a retroactive ban was **polyvinyl chloride** or PVC. The government has received a recommendation to phase out PVC by the year 2000, notwithstanding the presence of two million tonnes of accumulated PVC product in Sweden, and an estimated 350,000 tonnes in landfills. Further, given that more than 200,000 tonnes of electrical and electronic products are scrapped annually, a majority of them through incineration, legislation requiring manufacturers and importers to take responsibility for them as of 1998 is now being proposed by the Swedish EPA (Beverley Thorpe, workshop). The target is to have 85% by weight of electronic and electrical waste managed in a more environmentally benign manner by the year 2000 (Business and the Environment 1995).

Generally, several governments are enacting or considering shifting the burden of taxation away from income and profits and towards resource use and generation of pollution. Others are creating incentives for innovative pollution control technologies. For example, the Netherlands allows companies investing in such technologies to deduct the full amount of expenditures from taxable income in the first year, rather than over the usual 10-year depreciation period (Focus: National Center for Manufacturing Sciences 1995).

In Germany, the 1986 Waste Act requires certain manufacturers to reclaim their products once they are no longer useful. Most recently, major manufacturers, such as Xerox, are encouraging leasing of products for ultimate return to the manufacturer so casing and other parts can be used in the production of newer models. Similar product stewardship is being exhibited in the automotive industry, including possible return of spent cars to the manufacturer for disassembly and recycling into new products. Two other thrusts are to reduce the pollutant content of waste, thus enabling further recycling, and to reduce the amount of household waste by reduction in packaging materials.

Workshop Deliberations

Pollution Prevention in the Agreement

Participants at the March 1995 Pollution Prevention Workshop in Ann Arbor were asked to consider a series of questions, one of which was, "Does the current Agreement sufficiently address the policy of pollution prevention and provide ample opportunity for binational cooperation and collaboration?"

Participants felt that pollution prevention was imbedded in the Agreement as noted earlier, and was identified as an important technique towards attainment of virtual elimination by the Commission's Virtual Elimination Task Force. Pollution prevention was seen as one of a suite of programs and options, none of which should support practices inconsistent with pollution prevention. A possible role for the IJC was considered to be to promote some principles to the U.S. and Canadian governments to provide clarity and guidance, including perhaps a set of specific objectives for pollution prevention, in the basin community. An ethic for pollution prevention could be a part of this outcome. These suggestions could find form in Commission Biennial or special reports.

An additional question asked at the workshop was, "Are the governments fulfilling the intent and purpose of the Agreement in the area of pollution prevention?"

Several current voluntary and mandatory approaches were reviewed. Some preliminary observations were:

- regulations are a necessary antecedent to effective voluntary programs
- pollution prevention is more broadly based than government and industry and extends to all levels of society
- programs should be accompanied by clearly defined goals and objectives, developed as appropriate in a global context
- government support and initiation of general pollution prevention education efforts, including those associated with energy use, is strongly advocated as one means of indicating and encouraging the development of clean technology and clean production.

Some concern was expressed specific to the American program that, in a time of budgetary constraints, states may not elect to complete the transfer of program initiatives initially funded by the federal government as originally intended in pollution prevention legislation. It was also suggested by some that the Commission should query the United States and Canada on implementation of the new budgetary and deregulatory measures and their impacts on pollution prevention programs.

Prominent among the barriers cited to effective pollution prevention programs were those in U.S. legislation that could respond to certain voluntary pollution prevention initiatives by declaring facilities hazardous waste sites under the Resource Conservation and Recovery Act. The need for the government to continue to focus on its own practices was also emphasized.

It was suggested that an extraordinary effort to reopen the Agreement and alter it to better reflect a pollution prevention approach was not warranted at this time. However, as a renegotiation of the Agreement may well occur in the next few years, any opportunity to enhance its pollution prevention aspects should be taken. In the meantime, the Water Quality and Science Advisory Boards and the Commission could encourage the Parties to further refine the pollution prevention approach and identify a binational role for this approach to protect the Great Lakes through establishment of specific needs and a strategy for their further promotion.

Generic Characteristics of Pollution Prevention Programs

Widely accepted characteristics of pollution prevention and associated programs include:

- a focus on source reduction and on-site application
- emphasis on multi-media concerns as opposed to earlier single medium approaches
- exclusion or diminuation of waste treatment or pollution control, including off-site recycling and incineration or combustion where energy or product are not recovered
- provision of technical assistance, including on-site technical advice, training and education via means such as information clearinghouses and newsletters
- interaction with generators on a voluntary basis
- establishment of plans and targets, with measurable outcomes and reporting requirements, by participating facilities
- exploration of means of providing data on plan outcomes directly to the public
- use of other outreach options, such as award programs, to encourage further participation

(Canadian Pollution Prevention Legislative Task Force)

Measurement of Progress

A second group considered the question, Is a detailed assessment of current pollution prevention activities in the Great Lakes basin feasible and timely and, if so, how should progress be measured?

As noted previously, consideration of the measurement question often begins with a review of the **Toxics Reduction Inventory** (TRI) initiative of the U.S. EPA. This inventory, developed under Superfund Amendments and Reauthorization Act (Title III, Section 313) of 1986, requires certain manufacturers to report annually to the EPA on routine releases of designated chemicals to the air, soil and water. In turn the agency compiles this information into a Toxic Release Inventory and makes it available to the public in various forms, including a computerized data base.

One of the outgrowths of TRI was the 33/50 Program, established in 1988 under the U.S. EPA Office of Toxic Substances as a voluntary source reduction effort aimed at curtailing the release of 17 specific chemicals. The established target was to lower releases from an aggregate of .64 billion kilograms (1.4 billion pounds) in 1988 to .32 billion kilograms in 1995, a 50% reduction. An interim reduction of 33% was to be achieved by 1992; success would be tracked through annual TRI reports. To date, over 1,300 companies are involved and the EPA has determined that the interim target has been met and are confident that the 50% reduction in 1995 will be achieved.

In the Great Lakes region, EPA estimated that the 33% goal for the end of 1992 was exceeded, with total reductions of 85,500 tonnes (188 million pounds). It also appears that performance will surpass the 50% reduction goal for 1995 (Michelle Jordan, workshop). Not all of these reductions are due to activities within the bounds of pollution prevention; however, they do represent a very significant achievement.

The establishment of the TRI predates the U.S. Pollution Prevention Act of 1990. Recognizing that the inventory was not initially designed to delineate source reduction or pollution prevention initiatives specifically, that latter legislation included a provision that annual TRI reports henceforth "shall include with each such annual filing a toxic chemical source reduction and recycling report." These data are also to be made publicly available.

Concerns have been expressed regarding the use of the TRI to quantify reductions specific to pollution prevention. Beyond the question of the quality of the original estimates, some concerns include the complexity of adjusting for varying production levels, possible underestimation of the long-term contribution of pollution prevention efforts; unavailability of metering devices to measure critical quantities, differences in interpretation among similar reporting facilities, and the ability of a few large facilities to superficially distort regional trends (AWMA Summary 1992).

Indeed, a major concern regarding the TRI is that it accounts for only a small fraction (less than one percent) of the estimated over 10 billion tonnes of industrial pollutants generated in the U.S. annually (David Allen, workshop). Because it was not initially established to track pollution prevention efforts, it remains difficult to separate associated reductions from others that curtail release through increased application of waste treatment and control technology. Application of a materials tracking system is seen as a far more comprehensive method of tracking the status of particular pollutants (David Allen, Critical Review AWMA 1993). Notwithstanding these limitations, there was consensus that the public focus on pollutant reduction under TRI had a marked salutary effect on the attributed sources.

The Canadian government initiative, the **National Pollutant Release Inventory** (NPRI), shares several of the features of the TRI. It is a voluntary program, formally initiated in the spring of 1994 and currently tracking 178 contaminants from 1,466 facilities. Substances already regulated, such as pesticides or chlorofluorocarbons, are not included in this list. Tracked releases for 1993 total 225,000 tonnes, with sulphuric acid, methanol, ammonia, copper (and compounds), zinc (and compounds), and the organic solvents xylene and toluene being the largest individual releases. These data are available to the public on an electronic database.

The stated intent of the NPRI is to encourage development of pollution prevention plans; as the first data have only become available, the capacity of the system to track progress specific to pollution prevention cannot be immediately determined.

Another federal initiative in Canada is the **Accelerated Reduction/Elimination of Toxics** (ARET) program. It is a voluntary program developed through a multi-stakeholder process focused on persistent bioaccumulative contaminants. The 14 listed A-1 substances are targeted for virtual elimination, with a target of 90% reduction by the year 2000. For the balance of 87 substances, the goal is reduction to levels insufficient to cause harm, with a short-term reduction goal of 50% by the year 2000. The suggested base year to determine progress has been set at 1988.

In the first ARET progress report, the participation of over 200 facilities - private and public - has achieved a reduction of 10,300 tonnes of the selected 101 contaminants since 1988. Emissions of high priority A-1 chemicals has been reduced by 49% from among the user community and total reduction of ARET listed chemicals stands at 37%. Details on the methods for progress reporting are presented for each company; a majority are also reporting under the NPRI.

While they are indicative of progress toward limiting toxic releases into the environment, neither system is dedicated to an exclusive quantification of reductions based solely on a pollution prevention approach.

In considering the question of feasibility and timeliness of a possible detailed assessment of current pollution prevention activities in the Great Lakes, the Commission was encouraged to recommend that governments develop the capability for such a specific measure. It was suggested that perhaps the performance of specific sectors be reviewed to determine the extent to which application of pollution prevention techniques had been successful.

With regard to how progress toward pollution prevention should be measured, the discussion first recognized that no consensus definition of pollution prevention was available. The absence of a single definition resulted in a determination that any inventory must be multi-media and account for non-point inputs, including those associated with air deposition.

Broadening Pollution Prevention Activities

Among the questions posed at the March 1995 Pollution Prevention Workshop were: i) what are the most important cultural socio-economic and human factors influencing pollution prevention efforts and how should they be addressed to sustain progress? and ii) is pollution prevention sufficiently recognized by financial and industrial senior management to lead to a fundamental re-engineering of production equipment and processes?

Pollution control measures traditionally restricted discharges of potentially hazardous substances before they entered the environment. The recognition that "pollutants of concern" exist and present a sustained threat to ecosystem health brought about a shift toward a chemical-specific approach, consisting of both intensified pollution control measures and the reduction in use and generation of these substances.

This focus has progressed significantly from an "end-of-pipe" approach to a holistic view of waste reduction. Essentially, any generation of waste products (i.e. those which cannot be reused, either in that or another process stream) or inefficient use of energy is also a loss of resources. Frequently revenue is a prime motivator in encouraging current pollution prevention practices.

The fundamental and relatively broad question continually applied in the pollution prevention philosophy is, Why is waste being generated? Why are processes not more energy efficient? Why aren't materials utilized that optimize productivity without harm to the biosphere and human health? Searching for answers to these general queries has led industry on a voyage back "up the pipe." By scrutinizing each individual step of the process - from a product's design to its ultimate loss of utility - the responsibility for sound environmental and social practices can be shared by all participants in the transaction from producer and distributor to consumer (Wayne Pferdehirt, workshop).

Organizations such as 3M have moved beyond the traditional, corporate-wide environmental priority-setting exercises in favour of a wide-sweeping agreement that waste must be reduced. In their view, chemical-specific waste reduction priorities are less desirable as they may exclude some members of the workforce; establishing a broad waste reduction goal and encouraging individual participation in each area of expertise fosters a sense of responsibility and accomplishment for everyone. "Rather than have 10 individuals within an 'environmental division' try to develop solutions for processes with which they may be unfamiliar, organizations can now have, in some cases, thousands of people striving for solutions and approaches, perhaps to problems which would otherwise have been overlooked" (Thomas Zosel, workshop).

Design for the Environment

The pollution prevention perspective has most recently come to be applied to the first stages of a product's lifecycle, its design. "Industrial Ecology" has emerged as a cornerstone to this rethinking; it is defined in essence by Graedel and Allenby (1995) as,

> "...the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surroundings, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to components, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital."

By considering industrial systems as somewhat parallel to natural systems, within which any and all available sources of useful material or energy are used by some organism, designers have begun to consider the fate of their products in the industrial, recycling and waste streams (Robert Frosch, workshop). The evolved Design for the Environment tools are often referred to as Design for Disassembly, Design for Recycling, Cradle to Grave, Cradle to Cradle, and Cradle to Reincarnation. Each approach strives to minimize generated waste through the incorporation of recyclable materials, removable/replaceable or snap-in/snap-out parts, or take-back items which can be reused in new products.

As a measure of the effectiveness of such modified processes, **Life Cycle Analyses** (LCA) are often employed. The **Society of Environmental Toxicology and Chemistry** (SETAC) defines LCA as,

> "...an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire lifecycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling; and final disposal."

This 'quantifying measure' allows particular areas of energy imbalance to be identified and dealt with, thereby increasing the effectiveness of the entire process. Surprisingly, in many cases, the alternative which appears to be the most environmentally sound frequently requires a very significant energy expenditure for the extraction of materials or the transportation of goods, costs which are extraneous to the manufacturing regime per se but are nonetheless reflected in the final price of the goods and the total use of resources. It is crucial that such energy expenditures are included in any quantification of the impact of any process on the larger ecosystem. Although originally designed for simple products such as disposable diapers and drinking cups, LCA are now considered for more complex goods such as television sets and automobiles as their development continues (Graedel and Allenby, 1995).

Educational Challenges

In the industrial forum, much of the success in organizations such as Motorola and 3M is due to corporate-wide education programs. Because a great diversity of educational backgrounds of the employees must be taken into account, an approach quite different from that of an academic institution is necessary. Rather than lecture-style seminars, "action or exercise oriented" programs are developed to allow for "train-the-trainer" interactions to occur (Eagan et al. 1994). This allows individuals, who are experts in their particular area to participate optimally in discussions and brainstorming activities. Each employee may then offer his/her creative solutions, backed with a sound knowledge of the gains to be made, and a competent understanding of the issue. Effective training and education is a vital underpinning for a successful pollution prevention program in any given organization.

Academic institutions, such as the University of Michigan's **National Pollution Prevention Center** (NPPC), have instigated a "multi-sector perspective" (Jonathan Bulkley, workshop) to pollution prevention. Faculty members incorporate the most current pollution prevention idealogies into their curricula and demonstrate the relationship of pollution prevention to concepts in each discipline including architecture, chemistry, operation management, business law, accounting, chemical engineering, industrial engineering and industrial ecology.

> "Faculty in engineering, business and industrial design need to treat environmental issues as an important element of their design and management courses. Until a greater number of faculty and administrators recognize the value of such innovative topics, teaching in this area will only occur sporadically."
> (Keoleian and Menerey, 1994)

The NPPC has called for a national network of pollution prevention educators to facilitate in the "development and dissemination of pollution prevention education resource compendia" (Jonathan Bulkley, workshop). A national directory of faculty involved in pollution prevention education is available and is a valuable resource for students and staff.

Extending the Circle

Pollution prevention frequently is of financial benefit to corporations and consumers; however, it is typically driven by a suite of established performance values: the drive to be more efficient, more productive, more cost effective, more profitable. These traditional performance values, although often effective measures of the use of scarce resources, tell us nothing about how any technological development will fit into and be compatible with human life, society and nature (Vanderburg and Khan, 1994).

The societal context of chosen actions is frequently de-emphasized, although it could be a source of the very values which determine the nature of the ecosystem left for future generations. If the improvements created by pollution prevention are to be sustained and enhanced, human, societal and ecosystemic values must be given higher, if not equal, priority to these traditional performance measures in technology development. Full consideration of healthy workplace design, sustainable healthy cities, worker health and wellbeing, and quality of life is a necessity in modern manufacturing (Willem Vanderburg, workshop).

The incorporation of social factors as an additional measure of progress, particularly in Life Cycle Analyses Impact Assessment, can achieve a balance among financial, environmental and societal costs. Vanderburg (1995) explores the complex interconnection between technological advances and societal/human impacts with the query,

> "Will the plant (or facility) produce higher levels of nervous fatigue? If so, how will this affect the employees, the social relations they enter into at work, in their families and communities and thus the entire social fabric of a society? How will the...designs affect the integrity and viability of the ecosystem in which they will function?"

Ultimately a process which is both financially and environmentally beneficial, yet degrades societal or human values, may be discarded based on this larger deleterious impact.

Many organizations recognize that total review and examination of the selection of materials, product design, marketing strategies, and the product's ultimate fate, is an evolving philosophy at the base of future corporate policy.

A rerouting towards more societal-based impact assessment may be aided by modified educational programs that more accurately reflect the impacts on society. Vanderburg and Khan (1994) examined the formal engineering curriculum of a leading North American university to identify "the extent to which students learn to incorporate an understanding of how technology affects human life, society and the biosphere into engineering theory and design in order to ensure a greater compatibility between technology and its contexts." The categories examined included lectures, texts, tutorials/labs, and faculty publications. On a scale of 0 (No reference to context issues) to 4 (Substantial reference to context with an evaluation of consequences), overall curriculum scored only 0.8, and research publications only 0.3. This result indicates that "most of the courses are contextless" (Vanderburg and Khan, 1994), and that the engineering community "continue(s) to produce new generations of engineers who will approach the negative implications of technology for human life, society and the natural ecology in an "after-the-fact" or "end-of-pipe" manner" (Willem Vanderburg 1995).

Courses, and ultimately the manufacturing process, need to incorporate preventative strategies to reduce or entirely avoid negative implications in the societal or human context (Vanderburg, workshop). Negative feedback can be used to recognize and isolate design weaknesses, thereby allowing for appropriate corrections before they can detrimentally impact the outcome. Building negative feedback into corporate-wide strategic planning and product and service development could create "win-win" situations for all parties involved, from the corporation who will break the mitigation cycle, thereby reducing costs and wasted energy, to the consumer who can invest in sound products that don't detrimentally affect the health of their families or the ecosystem (Willem Vanderburg 1995).

By identifying the limitations of current tools and approaches, the assumption that they are the complete solution to our pollution concerns is effectively diminished. Innovative technologies avoid "end-of-pipe" solutions, and instead seek and continually adjust for an balance in which appropriate societal values are reflected in the manufacturing process.

Technology As An Enabler

Introduction

Technology is broadly defined as the means and process by which society produces the substance of its existence. It comprises five basic elements: tools/machines, energy, materials, skills and organization of work. The particular combination of these elements determines the technological path of society, and ultimately the efficiency of the operation and the waste generated. According to Nathan Rosenberg (workshop, 1995), the development of technology is fundamentally a market decision, driven by forces endogenous to the larger economy. Because of the relative abundance of space and natural resources, an inherently resource-intensive industry has been established in North America that substituted natural resources, wherever possible, for relatively scarce labour and capital.

The economy of the Great Lakes region exemplifies this, as it is founded on strong natural resource advantages: water, coal, iron ore, timber and mineral deposits. The sheer scale of human enterprise required to convert virgin resources into materials for processing, manufacture and ultimately wastes, both residuals and obsolete products, has created a problem and a challenge similar to the paradox of technology itself: the industrial economy, provides societal products and benefits, but also causes environmental damage and offers the technical means to repair that damage (Federal Reserve Bank of Chicago and The Great Lakes Commission, October 1985; National Academy Press 1989).

In order to manage technological change to address environmental problems, the role of research and development in encouraging innovation, development and diffusion of technologies must be understood. Rather than a linear process arising from the methodical application of basic research, the economic view of technology suggests that market forces are most pertinent to the role of technology. Their role is primarily one of finding new ways of delivering products to markets at lower cost.

> "The process by which new technologies come into the world is much different from the path suggested by the linear model; one way of seeing this is to look into the composition of **research and development** (R&D;) activity. With U.S. Research and Development, what becomes immediately apparent is that it is mostly development. In fact, for several decades now, development alone has constituted two-thirds of R&D.; One-twelfth of all R&D; is spent on basic research - research motivated purely by scientists asking fundamental questions about the nature of the universe - without any concern for practical applications. The rest, about a quarter of R&D;, consists of applied research.
>
> The great bulk of R&D; is spent on improving old products. If you ask vice presidents in charge of research in big American firms what they are spending their research money on, improving old products or inventing new ones, they reply that about 80% of R&D; goes to improving or modifying old products, and only 20% to developing new ones." *Nathan Rosenberg*

Thus, it is largely immediate and short-term market opportunity that is the significant driver of R&D; carried on at approximately 12,000 scientific research laboratories operated by private industry. Given this capability, and the nature of the R&D; enterprise, it is clear that the initial success of early pollution prevention efforts, often characterized as the harvest of low-hanging fruit, needs to be augmented by economic policies that encourage market behaviour based on full environmental costs, and incentives to promote research on the dual goals of green design: waste prevention, and improved materials management (U.S. Congress, Office of Technology Assessment October 1992).

Waste Prevention: Green Chemistry

The role of scientific research in the chemical industry in the United States is more closely allied with innovation, development and production than in any other industrial sector. It also comprises a larger share of basic research as a percentage of total R&D; effort, and is ranked at the top in terms of total R&D; financed by private funds (Rosenberg 1994). As external costs of potential environmental liabilities and pollution control increase, the attractiveness of benign organic synthesis, i.e. a method of avoiding the formation of hazardous substances, yields a focus beyond the creation of the target molecule. Management of reaction byproducts, many of which formerly ended as wastes to be managed, reused, recycled or ultimately released to the environment, is now a crucial consideration.

Dr. Russell Farris, of the Office of Prevention, Pesticides and Toxic Substances, U.S. EPA, presented an overview of the emerging field of green chemistry to the pollution prevention workshop. The summary which follows is based extensively on his transcript.

One of the primary criteria for evaluating a synthetic pathway in the manufacture of a chemical product is the yield of the process. Yield has been traditionally taken as a good indicator of thermodynamic favorability of a particular process under given reactions or manufacturing conditions. From an economic point of view, the yield is, of course, important as an indicator of the efficient use of the feedstocks. Historically, process path selection hinges on the selection of a feedstock. There is no doubt that the selection of feedstocks, based on cost and availability, and the use of yield in evaluating a synthetic scheme, will continue to be crucial considerations in chemical manufacture.

However, in view of the increasing costs of waste disposal, treatment and regulatory compliance and the current emphasis on pollution prevention, both by regulatory agencies and the chemical industry, evaluation of a particular synthetic method based solely on maximum yield is no longer valid. Rather, new methodologies may be designed that value an environmentally benign process.

This area of research meets both the chemical industry and society's needs to implement the concept of pollution prevention, and the academic community's need to focus on basic research. The next generation of synthetic chemists will certainly focus on how to build new chemical structures, but they will also be encouraged to incorporate all of the impacts - scientific, economic, social and environmental - into their process selection.

Under a pollution prevention umbrella, design of a chemical product begins with decisions about:

- What hazardous wastes will be generated?
- What toxic substances will be involved in the process?
- What toxic contaminants might be in the product?
- What liability concerns are there from the manufacture, use and disposal of this product?
- What waste treatment costs will be incurred?

By incorporating consideration of all of the scientific, environmental and economic impacts of a particular process from the outset, the proper pathway resulting in effective pollution prevention can be selected.

For many years, the environment movement and specifically the regulatory agencies have concentrated on ensuring that chemical products do not pose unacceptable risk. The focus has since been extended beyond the final product, to all of the substances associated with the manufacturing process. A few of the materials to be considered are:

- feedstocks
- byproducts and impurities
- reagents
- catalysts
- reaction media
- separation solvents
- distillation products

Approaches to Green Chemistry

The vast majority of commercial chemicals produced in the United States today is derived from petroleum feedstocks. While some petroleum feedstocks are environmentally benign, many others, such as benzene, a known carcinogen, are acknowledged as quite hazardous. This has spurred research on alternative feedstocks to petroleum, such as other, more easily renewed biological starting materials. In addition to their short-term renewal cycle, this type of biological feed-stock, unlike petroleum feedstocks, is often highly oxidized and highly functionalized, which allows for cleaner transformations and often eliminates the use of heavy metal catalysts.

The chemical industry has begun a review of the feedstocks and processes historically used in the manufacture of some of their most basic products. Monsanto, in the production of aromatic amines, is developing a method of direct amination of nitrobenzene rather than continue the use of hazardous chlorinated aromatics. They are also pursuing urethane and isocyanate production using carbon dioxide rather than the acutely toxic phosgene.

Dupont is using manufacturing methods which incorporate in-situ generation techniques, to reduce the risk of exposure to hazardous substances. These techniques have been applied to processes that use especially toxic substances, such as methylisocyanate, in agrochemical processes.

Alternative Catalysts

Some widely used materials in the chemical industry are also commonly recognized to pose significant hazards. Fluorinating agents such as hydrofluoric acid are well known for both their efficacy and their hazards. Air Products, Inc. has developed a fluorinating reagent that requires no special handling and performs selective fluorinations on a wide variety of substances.

Catalysis promises to make an increasing number of chemical manufacturing processes not only more efficient, but also more environmentally benign. Investigations into new applications of nontraditional catalysts to reduce the environmental impacts of certain reaction types, include the use of light energy as a catalyst.

Computer Design of Synthetic Methodologies

Over the past 25 years, the application of computer software to design synthetic transformations of entire pathways has been attempted repeatedly. Some of these computer programs use extensive databases, some work through logic programs and some through the use of artificial intelligence. The U.S. EPA is promoting the incorporation of environmental considerations into the current major software design programs, as well as the development of new software.

Solvent Alternatives

The environmental consequence of organic solvent use in the manufacture of chemical products has been an issue of concern for many years. The new U.S. **Clean Air Act Amendments** (CAAA) list many **volatile organic compounds** (VOCs), commonly used as solvents, as hazardous air pollutants. A number of ongoing research projects have a goal of reducing the amount of VOCs released by the chemical industry.

One alternative is the use of **super-critical fluids** (SCFs) as a reaction medium. While the usefulness of SCFs as an extraction solvent, a cleaning solvent or in analytical methodologies has been well established, the use of super-critical carbon dioxide (as well as other SCFs), as a reaction medium is now emerging. Recent documented successes include the use of SCFs as a medium for polymerization reactions, free-radical transformations, and in certain catalytic transformations.

Another approach is the increased use of aqueous reaction systems, rather than the established procedure of using organic solvents for synthetic transformations.

With the goal of VOC solvent reduction widely embraced, an obvious alternative is the greater use of solventless and solid-state chemistry. Such reactions do not generate any waste solvent, thus availing disposal or recycling. Solid-state chemistry has the additional advantage of operating under very low vapour pressure, which minimizes the exposure of workers to any inhalation hazard.

Curriculum Development

The incorporation of environmentally benign synthetic techniques into the chemical industry will be accelerated well into the foreseeable future. For these reasons, the U.S. EPA has promoted the development and use of educational materials to formally train students of chemistry and associated sciences at various levels of their education to more fully consider environmental impacts. The materials include:

- Textbook supplements, which parallel the classical chemistry texts but offer environmentally benign alternatives to standard techniques.
- A reference module for faculty, to translate the most recent environmentally benign research into their classroom presentations.
- Laboratory modules that illustrate the experimental principles of benign chemical synthesis through undergraduate experiments.
- Professional training for industrial chemists to demonstrate why pollution prevention is desirable and how environmentally benign chemistry can achieve it.
- The **National Center for Clean Industrial and Treatment Technologies** (CenCITT) has involved industry, government and academia in devising clean enabling technologies and design tools. There are three main elements to this effort: i) Chemical Reaction Pathways, Efficient Materials Utilization and the **Clean Process Advisory System** (CPAS). The first seeks to limit or eliminate creation of byproducts; the second to reduce or eliminate waste and reuse secondary materials, including design for disassembly; the goal of the third, CPAS, is a national computer-based framework that provides information on new environmental and pollution prevention technologies, methodologies, costs, safety and compliance (Focus, National Center for Manufacturing Sciences April 1995).

Synthetic or "green" chemistry has an important and fundamental role in the environmental movement. Through development of appropriate training, knowledge and expertise, chemical synthesis processes can be selected or altered to ensure that environmental impacts are minimized. While there are numerous situations where other pollution prevention solutions or even pollution control measures are appropriate, green chemistry should be the option of first choice, and built into the earliest stages of planning when synthesizing a chemical product.

Materials Management

Much of the solid waste produced in the United States is not directly generated by individual consumers. Municipal solid waste, the focus of much public concern, represents less than two percent of all solid waste regulated under the U.S. Resource Conservation and Recovery Act. In contrast, industrial activities from all sectors produce about 700 million tons of hazardous waste and about 12 billion tons of nonhazardous wastes per year (U.S. Congress, Office of Technology Assessment October 1992; David Allen, workshop). Total waste generation in the United States represents a vast throughput of material, with relatively little recovery (David Allen, workshop). Rather, most goes to land-based disposal, or various forms of incineration.

In assessing the value of wastes as raw materials, it is important to consider both the flows and quality of materials as analogous to the recovery and refinement of virgin resources. It has been estimated that, with the exception of mercury and lead, large quantities of other materials are not being recycled. In some cases, this includes relatively concentrated waste streams that should be competitive with virgin materials (David Allen, workshop).

> "The problem is not waste management, the problem is materials management; where materials go and how they are used. It is a peculiarity, at the least of the U.S. system, that on the virgin materials side, all sorts of heavy metals and toxic substances move relatively easily with regulations that keep them fairly safe, but the instant they become wastes, the regulations become contorted and complicated. There is something odd about the two sides of the system. They behave very differently, and yet they ought to be connected in the sense that technologically the output side should become part of the input side, but we have a kind of schizophrenic approach to dealing with it." *Dr. Robert Frosch, John Fitzgerald Kennedy School of Government, Harvard University*

In reviewing the barriers to the efficient use of materials (virgin or recycled), Dr. Frosch introduced participants at the Pollution Prevention Workshop to the aid, LOITER:

- **L**iability
- **O**rganization
- **I**nformation
- **T**echnology
- **E**conomics
- **R**egulation

The barriers associated with each of these elements are not necessarily in any particular order or rank; they tend to be nested within each other. If a particular industrial use of materials, or the reuse of the material, is technologically possible, it may not be economically feasible. If it is technologically and economically feasible, the information necessary to support acceptance and practice may not be widely available. When these matters are resolved, there still may be internal and external organizational barriers. Even in large well-integrated companies, technology often does not easily cross barriers, even when the information is available, due to other management or organizational difficulties. Incentives may not be sufficient for diffusion of technology even if it is economical and even if the information is readily available to encourage adoption (Robert Frosch, workshop).

To attain material and energy efficiency and avoid a one-way flow of materials, a broad view of the industrial system, evolving towards a closed system, is necessary. Such a system is viewed not just in terms of controlling and managing wastes by one user, but rather in terms of sequential uses of materials by other industrial sectors. This view of wastes as "material" should include both residual wastes and obsolete products.

Such an approach suggests broadening the design of product and process to include the intentional design of the byproducts and the waste materials. Reuse of the latter does not necessarily occur in the same facility or in the same industry as well; rather, such materials could be available to anyone in the marketplace. The issue becomes not whether a waste coincidentally can be used in some later process, or otherwise be beneficial, but rather whether it is a resource deliberately made available for use by the whole economic industrial system, thereby contributing to improved efficiency and sustainability.

> "This is obviously a very complicated question and one that is unlikely to be dealt with by actually designing the system and attempting to implement it. It is more likely to evolve by putting incentives into place that encourage industries to work with each other to develop such an "industrial ecosystem." The feedback value of incentives is important so that the use of materials is considered not only in squeezing the most economic value out of material inputs through the design of the product, but also in terms of someone's eventual reuse. Of course, regulatory mechanisms could also play a role. I regard "takeback" legislation as simply being an attempt to put a feedback loop into the industrial system. It is not necessarily the case that the producer of the material will be the best one to reuse it. While this may frequently be the case, in some instances, it will be elsewhere in the system where the best reuse will be found."
>
> *Dr. Robert Frosch, John Fitzgerald Kennedy School of Government, Harvard University*
>
> An Ecosystem Approach

In pollution prevention, a range of scales or limits encompasses lifecycle design to green chemistry. These can be delineated as follows: (David Allen, workshop)

- Macroscale:

  Lifecycle design/assessments, modelling and large-scale ecosystems. Flows of materials in regions and countries, and relationship with the biosphere.

- Mesoscale:

  Redesigning processes, facilities and their operation.

- Microscale:

  Molecular development through green chemistry and benign molecular pathways.

These three elements comprise a third generation of pollution prevention, following housekeeping initiatives and the separation technologies/material substitution (David Allen, workshop). At the macroscale, the critical tools are those related to pollution prevention measurement (an issue dealt with elsewhere in the workshop) and those allowing the assessment of material flows in products and sectors, so that critical waste streams can be targeted for pollution prevention. At the mesoscale, the development of quantitative flow-sheet analysis methodology to permit the systematic analysis of processes could enable a residual material from one process stream to be transferred to another process stream as input. One such approach, called Mass Exchange Network Synthesis, has relevance as an alternative to zero discharge as a goal for pollution prevention, where zero is not feasible (David Allen, workshop).

At the microscale, specific developments such as the use of water-based coatings, biocatalysis in chemical manufacture, and product design incorporating such standards as the new ISO14000, are all applicable.

Findings and Recommendations

The substantial progress made thus far under pollution prevention has occurred primarily from selective use of proven technology and improved management. The most significant challenge and opportunity, however, lies in the innovation, adoption and diffusion of new technologies and applications in the areas of waste prevention and materials management. Ultimately, the latter element includes consideration of product lifecycles, and is key to the creation of a sustainable materials economy. Such an approach requires the collaboration of government and industry in a Great Lakes regional materials management system, to support the development of secondary markets as an incentive towards efficient resource utilization. Such a management system is not envisaged in terms of a central planning authority, but rather as an important part of the market system to be implemented by industry.

1.1.5 Workshop Findings

General

- In the last half decade, the number of programs described as pollution prevention in effect in the basin has increased substantially. While initial regulatory efforts and frameworks were and are crucial, there is a strong emphasis on voluntary programs. Many industrial sectors and its associations are working with federal, state and provincial and local government agencies to tailor plans to the specifics of each sector and facility.
- Pollution prevention, in displacing the end of pipe or control approach, is successfully penetrating through the process management level to more senior executives in both the corporate and regulatory sectors. However, many of the myriad activities and practices in the basin are still not captured under voluntary or regulatory pollution prevention programs.

Quantification

- No common baselines or methods have been developed for a cumulative quantification of toxic reductions specifically due to pollution prevention programs and projects. Thus, in most cases, it is difficult to sum the achievements of the various preventative initiatives toward reductions in toxic discharges to the basin, both generally and toward the virtual elimination of persistent toxic substances goal in the Agreement.
- The traditional suite of performance measures (many of which are based on economic parameters) applied in the manufacturing and service sectors is not broad enough to accurately encompass societal, human and ecosystemic impacts of decisions. Measures of progress must be enhanced to include societal considerations as well as measures based on science and technology and traditional economics.
- There was significant support for a materials inventory, rather than a waste inventory, database management approach.

Modification of the Great Lakes Water Quality Agreement

- An immediate revision to the Agreement to elaborate on a pollution prevention approach was not deemed necessary. There was support, however, for the Commission involvement to encourage the development of guiding principles or ethics, as well as objectives for the extension of the pollution prevention approach.

Extension of the Concept

- Many pollution prevention activities have focused largely on industrial applications; further extension of a pollution prevention approach to numerous other sectors, including agriculture, transportation, merchandising, government and the individual household, would be appropriate. Use of a preventive approach on this broad scale will be necessary if desired progress is to be achieved.
- The pollution prevention approach, in its embrace of the Design for the Environment and Life Cycle Analysis, and through application of concepts such as lifetime product stewardship and further inclusion of the user or consumer, now extends beyond the boundaries of any given facility into the realm of broadly based social practice.
- A preliminary review suggests that the formal education process is not adequately attuned to providing students with a balanced understanding of the intricate relationship between science, technology and the societal context, particularly as applied to pollution prevention and ecosystem quality.

Technology

- Proven technologies with potential for more extensive application to pollution prevention include: design for the environment; renewable energy usage; and energy conservation information management.

- The greatest needs for technological innovation were identified as: separation technologies; improved process design; and further implementation of disassembly design.
- The most immediate and apparent benefit to be gained from pollution prevention efforts would be extending of the successes of major facilities and corporations to small business through:
  - one-stop shopping for regulatory and technical assistance
  - partnerships with larger, client industries to secure technical expertise on waste-management issues
  - a more extensive recycling infrastructure to accommodate smaller quantities of byproduct materials.
- Further incentives need to be identified and implemented to encourage the innovation, adoption and diffusion of technology that prevents waste generation through continuous process improvement, encourages efficient energy use, establishes a regional materials management system, and promotes the research and development of green chemistry.
- Full economic impacts need to be identified in any strategic planning process to ensure an orderly transition toward sustainable practices. The costs associated with development of feeder materials as well as the management of byproducts and the ultimate fate of the product must be considered.

1.1.6 Water Quality Board Recommendations

The Water Quality Board recommends that:

- **Should the Parties determine to re-open the Agreement, consideration be given to augmentation by a more thorough treatment of pollution prevention, including its designation as the preferred approach, extension of the breadth of the application beyond the municipal and industrial sources, and development of suitable guiding principles.**
- **The Parties reflect on their current inventory efforts to determine if reductions due to pollution prevention can be quantified, particularly of persistent toxic substances, and if the introduction of a material management, rather than a waste management, inventory would be timely and appropriate.**

1.1.7 Recommendation of the Science Advisory Board and the Water Quality Board

- **Significant regulatory barriers prevent extensive adoption of a lifecycle approach to the management of waste residuals and obsolete products as part of a sustainable materials economy. The Commission should encourage the systematic identification of these by the Parties to correspond with the goals and policy of pollution prevention. Lifecycle management should include the concept of reincarnation so that wastes are treated as resources, and managed as such.**

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*Chapter One:*Great Lakes Water Quality Board

1.2 Review of Developments in the Pulp and Paper Industry

1.2.1 Introduction

Seventy-two pulp and paper mills currently discharge effluent directly into receiving waters in the basin, 18 in Ontario, and 20, 20, 12 and 2 in Michigan, Wisconsin, New York, and Ohio respectively. Effluent limitations have been based on factors such as production process characteristics, product, quantity produced, the age and location of the mill, and the capacity of the receiving waters. Locations of these mills are given in Figure 1; the numbers correspond to those assigned to facilities in Table 2.

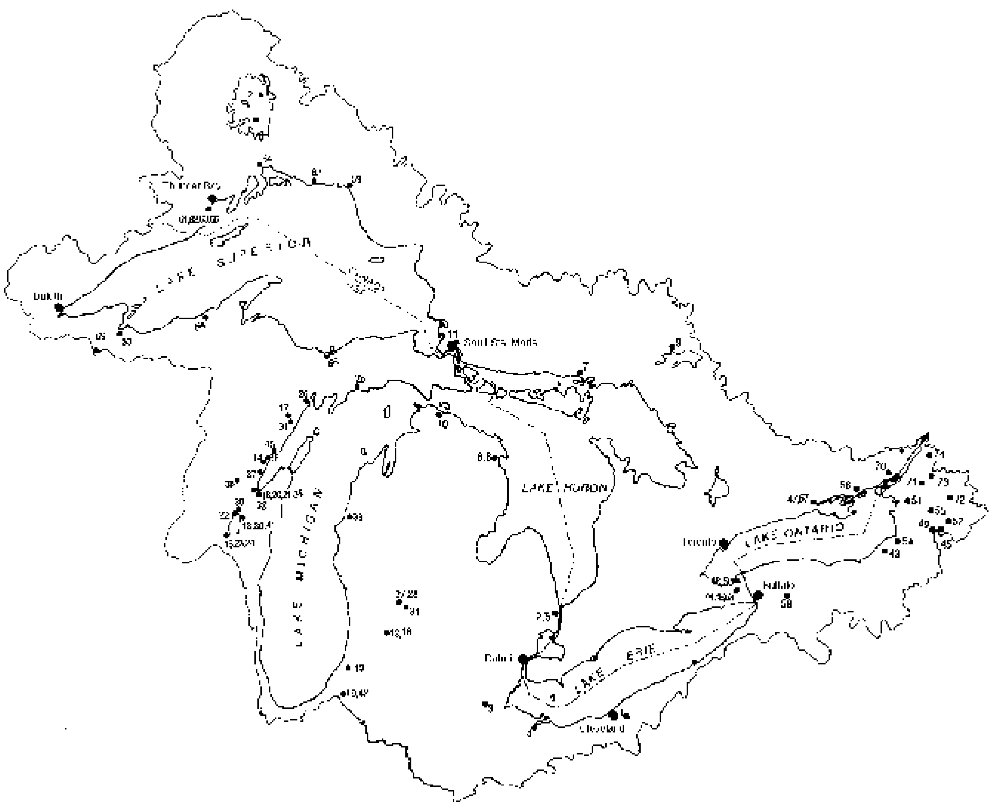
Traditionally the pulp and paper industry has played an important role in the development of northern communities in the Great Lakes basin, particularly in Canada's resource driven economy. In many, the pulp and paper industry is the principal employer and main source of tax revenue. This is especially true in northwestern Ontario, along the north shore of Lake Superior (Bonsor et al. 1988).

Discharges from pulp and paper mills contain conventional pollutants and chlorinated organic substances. Historically pollution abatement strategies have been directed at the conventional pollutants, which include **total suspended solids** (TSS) and **biochemical oxygen demand** (BOD). Pulp production results in considerable quantities of suspended solids and high BOD waste streams, which deplete dissolved oxygen in receiving waters and harm benthic organisms and fish if inadequately treated. Secondary treatment at many sites has led to a significant reduction in these conventional pollutants.

During the mid to late 1980s, studies by the U.S. EPA and the Ontario Ministry of Environment showed that bleached kraft pulp and paper effluent contained quantities of persistent toxic substances, including **2,3,7,8-tetrachlorodibenzo-p-dioxin** (TCDD) (the most lethal member of the dioxin family), and **2,3,7,8-tetrachlorodibenzofuran** (TCDF) (furan), in the subpart per billion concentration range, and numerous other undifferentiated chlorinated organics. These studies also noted the regulatory mechanisms by which other jurisdictions and nations planned to measure and control the release of these contaminants, in particular the use of **Adsorbable Organic Halogens** (AOX) in Ontario, or **total chlorinated organics** (TOCL) control in most European countries, and dioxin limits in the United States (WQB 1989).

The historical and current impact of pulp and paper effluent is evident in 15 of the 43 **Areas of Concern** (AOC) identified by the Water Quality Board as areas of significant degradation and ecosystem impairment in the Great Lakes basin.

Figure 1.
Pulp and Paper Facilities in the Great Lakes Basin
(See Table 2 for Facility Names)



1.2.2 The International Joint Commission's Interest in the Pulp and Paper Industry

In its 1990 *Fifth Biennial Report on Great Lakes Water Quality*, the **International Joint Commission** (IJC) recommended that Lake Superior be designated a demonstration basin to apply a policy of zero point source discharge of persistent toxic substances. With the exception of several localized areas, Lake Superior is recognized as the most pristine of the Great Lakes water bodies. Thus far, incoming pollutants from its relatively few point and nonpoint sources have been greatly diluted in its huge volume. Although a significant portion of the persistent toxic burden arrives via atmospheric deposition (International Joint Commission 1990), certain point sources have caused and continue to cause localized degradation and an increase in the loading of persistent toxic substances.

The zero discharge recommendation, focussing on point sources such as the pulp and paper industry, was the culmination of a longstanding interest in the conventional and toxic discharges from the forest products sector.

In the 1977 Appendix C of the Annual Report of the Remedial Programs Subcommittee to the Implementation Committee, the **Great Lakes Water Quality Board** (WQB) summarized basin loading trends, gave an overview of pulp and paper making processes, and outlined state, provincial and federal initiatives to regulate pulp and paper mill effluent (Great Lakes WQB 1977).

At that time, United States Environmental Protection Agency effluent guidelines focussed on **total suspended solids** (TSS) and **biochemical oxygen demand** (BOD) and reflected adoption of the **best practicable technology** (BPT) for specific mill types. In Canada, regulations and guidelines limited the discharge of TSS, BOD and substances acutely lethal to test fish species. Overall, American BOD standards were approximately three times more restrictive than comparable Canadian standards. Conversely, Canadian TSS limits were three times as stringent as those in the U.S.

In 1981, the Pulp and Paper Point Sources Task Force of the Water Quality Board, in *The Response of the Pulp and Paper Industry in the Great Lakes Basin to Pollution Abatement Programs*, reported on pollution abatement programs, effluent limitations, discharge trends, monitoring practices, and the industry's technological advances in the United States and Canada. The task force found that the industry had made significant reductions in conventional pollutants, yet further reductions were necessary to meet the objectives of the Water Quality Agreement. Moreover, the task force stressed the importance of identifying and removing toxic substances from pulp and paper mill effluent. Of particular concern were persistent and bioaccumulative substances, including chlorinated organic compounds. The task force recommended that practical measures be employed to reduce the production and discharge of these substances. Specifically, industry was encouraged to substitute chlorine dioxide for chlorine (elemental chlorine) bleaching and to improve unbleached pulp washing to minimize the carry-over of dissolved organic material into the bleaching process (WQB 1981).

The 1987 Water Quality Board report updated industry progress in reducing conventional pollutants and reviewed acute toxicity testing data from Ontario and Wisconsin mills. From 1980 to 1985, total loadings of TSS and BOD to the Great Lakes basin were reduced by 26% (from 144.5 to 106.2 tonnes/day) and 30% (from 384 to 269 tonnes/day), respectively. Further, pollution abatement at Ontario pulp mills was primarily responsible for these reductions. Further toxicity testing revealed that 14 of 20 Ontario mills had effluent lethal to test species, while that at 8 of 20 Wisconsin mills was lethal. Although the protocol for substantiating ratings of acute toxicity had at the time not been well established, six of the eight lethal mills were categorized as severely toxic (WQB 1987).

In 1989 the Water Quality Board noted that, despite significant reductions of conventional pollutants by the pulp and paper industry, it remained a major contributor of BOD and TSS to the Great Lakes basin. In Ontario, this industrial sector accounted for approximately 80% of all BOD loadings from industrial sources discharging directly into the basin, and exceeded the BOD and TSS discharges from all of the province's municipal treatment plants in the Great Lakes basin. The Board thus recommended that mills adopt secondary treatment or other equivalent pollution abatement technology aimed at reducing levels of conventional and toxic contaminants in effluents from these sources (WQB 1989).

A number of complex organochlorines are contained in bleached pulp and paper effluent, which could pose some hazard to aquatic life forms and remain unidentified. In the absence of an extraordinary effort, it is likely that many of these substances will remain unidentified. The IJC s report, *A Strategy for Virtual Elimination of Persistent Toxic Substances*, released in 1993, recommended that

> "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."

In response to this particular recommendation, coupled with restrictions on chlorinated organic discharges, particularly dioxin, the pulp and paper industry has begun to modify processes and feedstocks. Most recently the market and associated price for timber products was improved dramatically, allowing for investment in appropriate process modifications. The sustainability of the basin's forest industry is an ongoing interest of the Water Quality Board, which it hopes to comment on in the near future.

1.2.3 Effluent Characterization: Assessing the Potential for Harm

Effluent generated from pulp and paper mills is a complex mixture of components, each with its own characteristics, properties and potential hazards. Collectively these components present a challenge for the establishment of appropriate tests, monitoring procedures and control technologies. The composition of pulp mill effluent is largely dependent on the type of wood used, in-plant processes (including, in some cases, bleaching sequences) and the efficiency of the effluent treatment procedures. Unbleached pulp mill effluent normally contains resin acids and soaps, fatty acids, diterpene alcohols and phytosterols. If chlorine bleaching techniques are used, the effluent contains chlorinated phenols, chlorinated acids, alcohols, aldehydes, ketones and aliphatics as well as aromatic hydrocarbons. Numerous volatile sulphur-containing compounds may also be found in pulp mill effluent (Sprague and Colodey, 1989; Kringstad and Lindstrom, 1984). Chloroform and toluene may also be emitted in vapour form to the atmosphere.

Regulatory guidelines for the discharge of pulp and paper effluent traditionally relied on such quantitative, physical parameters as BOD and TSS. BOD, as an indicator of the presence of organic material, measures the tendency of an effluent to consume dissolved oxygen from a receiving water in the course of natural chemical degradation (Bonsor et al. 1988). Conversely, TSS measures the amount of solid organic matter suspended in water. The slow decomposition of fibrous mats, formed from those suspended organic solids, and other contaminants results in anoxic (oxygen poor) conditions and the formation of toxic gases in the receiving waters (Bonsor et al. 1988). Although these parameters remain integral in the overall assessment and characterization of effluent, the current legislative and scientific thrust is towards more organism-based, sentinel tools for measurement.

Testing, required by such regulatory statutes as the **Canadian Environmental Protection Act** (CEPA), the U.S. EPA's **Clean Water Act** (CWA), and the Province of Ontario's **Municipal/Industrial Strategy for Abatement** (MISA) has moved beyond the single-species acute and chronic toxicity test towards a multi-organism approach, to better represent the complexity of the ecosystem (Cairns 1986). In addition to standard 96-hour LC50 guidelines (to be discussed further), regulatory bodies are incorporating toxicological and histological examinations to ensure that any indicators of stress, particularly those at a biochemical level, are not overlooked. Governing bodies have also increased efforts to monitor contaminants of concern. However, no consensus has been reached as to which parameter, AOX or trace chlorinated organics, better represents the hazard associated with mill effluent.

Acute and Chronic Toxicity Testing

Incorporated into required effluent testing, acute and chronic toxicity tests have evolved from their original design as increased consideration is given to species selection, testing duration and design, and possible sublethal effects.

Toxicity may be assessed on an acute or chronic level. Acute toxicity measures the effect of effluent on lifeforms from short-term exposure leading to a relatively immediate crisis or end point, whereas chronic toxicity measures effects developing after continuous, long-term exposure to low doses of toxic material (Ontario Ministry of Environment 1988). Both acute and chronic toxicity can be manifest in organisms as sublethal or lethal effects. A sublethal effect indicates an impact on a given organism other than death, while lethal effects result in the demise of the organism.

Acute toxicity is generally measured using a 96-hour LC50 test. This test measures the percentage of an effluent, which, when mixed with clean water, causes a 50% lethality to test organisms over a 96-hour period. The lower the effluent percentage, the higher the toxicity (Ontario Ministry of the Environment 1988). For many organisms, the difference between acute lethality and non-lethal concentrations is small. Sudden, subtle fluctuations in whole effluent or individual components at or temporarily above the LC50 could result in the mortality of aquatic organisms in the immediate receiving waters of pulp mill discharges. This testing is often used as a factor in determining receiving water capacity, which assumes that the effluent will be sufficiently diluted upon entering the receiving water, an assumption which is not always met (Servos et al. 1992). Regulations which require "non-lethality at the end-of-pipe" avoid the difficulties inherent in this assumption.

Limitations associated with **Lethal Concentration** (LC) testing include the inability of the experiment to duplicate all possible in situ parameters. Physical changes in temperature, pH and dissolved oxygen levels in receiving waters are among the factors that may affect toxicity evident in the vicinity of the discharge.

Chronic toxicity may be expressed as decreased reproductive performance, biochemical or physiological change, morphological deformities, mutagenicity or carcinogenicity (Environment Canada/Health and Welfare Canada 1991). A chronic toxicity testing protocol is more difficult to design as outcomes are, in most cases, less dramatic than that of the acute procedure. It is therefore essential that more comprehensive monitoring procedures and testing protocol be developed to address this issue. The current pulp and paper regulations under the Canadian Environmental Protection Act of 1991 require testing to determine chronic impacts on early life-stage development of fish, preference/avoidance behaviour in fish, and invertebrate reproduction.

Subtle, sublethal effects which can pass relatively undetected within a population may cause significant harm. Behavioral modifications, which cause an individual to deviate from normal patterns, may alienate individuals from the population. In essence, although an individual has not died from exposure to a toxic substance, its inability to perform the appropriate mating ritual means that it cannot reproduce. The same can be said for an individual who fails to recognize danger due to reduced sensory perception. Although direct cause of death was due to predation, a toxic response was a significant contributing factor. These very subtle changes may provide the foundation for a consequential species shift and alteration of the ecosystem over time.

Current acute and chronic testing provides only limited information on potential effluent toxicity. Due to financial and technical constraints, "representative" species are selected from various rungs of the food chain in an attempt to characterize the overall impact on biota. Unfortunately, an effluent s LC50 is not a property; it is a biological response by the test organism. Thus estimating through, and extrapolation to, other organisms is significantly limited.

Current legislation requires that toxicity testing be carried out on whole effluent, thereby accounting for any interactions among components. It is difficult to predict the mixture's toxicity on either an acute or chronic scale. Bonsor et al. (1988) attempted to predict the toxicity of bleached mill whole effluent by estimating the contribution of each individual chlorinated organic compound (chlorinated catechols, guaiacols, phenols, resin acids and fatty acids) contributed to the overall toxicity (Environment Canada/Health and Welfare Canada 1991). Estimates so derived varied from 2.2 to 0.2 times the actual, observed acute lethal level.

Adsorbable Organic Halogens (AOX) vs. Trace Contaminants Analysis

Because of the variable and complex nature of mill effluent, it is unlikely that all chlorinated compounds in bleached pulp mill effluent will ever be identified or adequately quantified (Environment Canada 1991; Bonsor et al. 1988). Therefore, numerous jurisdictions have explored a surrogate means by which the hazard presented by this effluent mixture can be determined.

The Provinces of Ontario, Quebec, Alberta and British Columbia have chosen to regulate the discharge of organochlorines through the use of the sum parameter AOX. This technique involves passing an effluent or wastewater sample through activated carbon to adsorb organic substances. After the carbon is washed to remove inorganic halides it is combusted, and the gaseous products are analyzed for total halogens. In effluent from bleached pulp mills, the halogen (X) component is almost entirely chlorine (Environment Canada 1991).

Because AOX is a non-specific measure of halogenated organics, it does not identify classes of constituent chemicals or individual compounds. Thus the potential toxicity, persistence or bioaccumulative capacity of specific organic substances and of the total effluent cannot be derived, and AOX cannot be taken as representative of the relative toxicities of the constituent compounds. For example, mills discharging equal concentrations of AOX may exhibit very different toxicities (as measured by an LC50 test) due to the varying proportions of individual components (Holloran et al. 1992). AOX is effective, however, as an indicator of progress towards the virtual elimination of industrially discharged chlorinated organic compounds into the Great Lakes waters.

Environment Canada, along with the U.S. states in the basin, rather than utilize the AOX sum parameter, have adopted monitoring regulations for levels of individual organochlorines of concern. This approach is also favoured by a significant segment of the pulp and paper industry (McCubbin and Folke, 1995), who support regulating specific chemicals of a particularly toxic nature such as dioxins and furans. A limitation to this approach, however, is that only 10-40% of low molecular weight (mwt<1000) chlorinated components in bleached mill effluent have been satisfactorily characterized (Kringstad and Lindstrom, 1984). Because these low molecular weight compounds may present a greater risk due to their ability to cross biological membrane, many unidentified toxic compounds may be released into the environment without specific regulation or control.

An additional method of effluent toxicity assessment has been suggested to compensate for concerns surrounding both the use of AOX and trace contaminants. Through the use of **Toxic Equivalency Factors** (TEFs), the toxicity of the entire AOX mixture may be expressed as a ratio of the individual compound (or group) toxicity to the toxicity of a reference compound from the group. A specific application of this principle is the generation of **Pentachlorophenol Toxicity Equivalents** (P-TEQ) (Holloran et al. 1992). A similar technique has been utilized to equate total PCB congener content in fish and mussel fillets to 2,3,7,8-tetrachlorodibenzo-p-dioxin expressed in terms of TCDD-Equivalents (TCDD-EQ) (Williams et al. 1992; Hong et al. 1992). This technique would require more extensive differentiation of effluent components than the AOX sum parameter provides specifically to break the components into families or groups but would provide more accurate estimates of the total effluent toxicity than individual trace contaminant analysis may reveal. Table 1 expresses the toxicity of pulp mill effluent, from facilities which utilize chlorine processes, in terms of their **Toxic Equivalents** (TEQ).

Any technique chosen to characterize effluent toxicity, be it AOX, trace contaminant analysis or TEFs, must be sufficiently conservative to compensate for the various routes of exposure of each organism. Although effluent may be released at a "no observable adverse effects level" (NOAEL), organisms with specific lifestyle traits (e.g. benthic feeders) may be at a significantly greater risk of stress due to unique exposure dynamics than an organism with a different lifestyle.

Dioxins and Furans

The term "dioxin" commonly refers to a family of 210 structurally related chlorinated aromatic compounds, known as **chlorinated dibenzo-p-dioxins** (CDDs) and **chlorinated dibenzofurans** (CDFs). Dioxin toxicity is enhanced by the substitution of chlorine molecules in the 2,3,7 and 8 positions. The most toxic member of this family is 2,3,7,8-TCDD which is among the most potent toxicants known and a suspected carcinogen. Other potentially harmful dioxins and furans have the characteristic 2,3,7,8-substitution, however have additional chlorines in their structure (penta-, hexa-, hepta-, and octa-CDD/Fs). Accordingly, the toxicities of other dioxins are expressed in relation to 2,3,7,8-TCDD by using a Toxicity Equivalency Factor (TEF) described above (Bonsor et al. 1988). 2,3,7,8-TCDD has an assigned TEF of 1.0. The closely related compound 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is estimated to be one-tenth as potent as 2,3,7,8-TCDD; therefore, it has a TEF of 0.1. Although other dioxins have been measured in mill effluent, the pronounced toxicity of TCDD and TCDF has set them apart as important contaminants for study and regulation.

Table 1 contains 1993 toxicity estimates for pulp and paper mills which utilize chlorine processes. Mills which do not use chlorine-containing compounds (such as elemental chlorine, chlorine dioxide, or sodium hypochlorite) were not solicited for the "Quantitative Estimation of the Entry of Dioxins, Furans and Hexachlorobenzene into the Great Lakes From Airborne and Waterborne Sources" report, by Cohen et al. (1995) as they are not considered to be significant sources of dioxins and furans. This table was modified to include only those mills whose effluent is directly discharged to either one of the Great Lakes or a tributary thereof. Mills whose effluent is discharged to municipal sewage treatment plants were not considered within the scope of this chapter.

Data were provided to the Center for the Biology of Natural Systems (Queens College, CUNY) for inclusion in the Cohen et al. report by the **National Council for Air and Stream Improvement, Inc.** (NCASI) and the Ontario Forest Industries Association.

Prior to inclusion of Table 1 in this report, steps were taken to corroborate the data with several government sources. On the advice of the U.S. EPA, a search of the **Permit Compliance System** (PCS) was completed. A search for 1993-1995 data on the eight U.S. mills which are contained in Table 1 revealed 68 "No Data" entries, 2 "No Data Violation" entries, 9 "Less Than Average Maximum" values, and 1 "No Monitoring Required" status entry. Thus, no direct verification of the NCASI values was possible.

The State of Wisconsin was subsequently solicited for their assistance with the Wisconsin mill data. Because their permitting system requires monitoring only if results from analytical test during permit reapplication indicate the potential for exceedence of water quality based guidelines, limited data were available. However, their records indicate that no detectable level of 2,3,7,8-dioxin congeners has occurred in the effluent of Wisconsin mills since approximately 1989.

As mills are required to monitor and report effluent data under the Canadian Environmental Protection Act, the Ontario Forest Industries Association data were sent to Environment Canada for their scrutiny. Overall, staff felt that the data were representative of their records. Dioxin data for 1994 and the beginning of 1995 for Canadian mills were available, however as no equivalent U.S. data were available, those figures are not presented.

As footnote "c" in Table 1 indicates, TEQ values are estimated from 2,3,7,8-TCDD and 2,3,7,8-TCDF data only. Because the original submission from the Ontario Forest Industries Association was based on all dioxin congeners, and subsequently corrected to match the NCASI submission (which based TEQ estimates on the tetra (four) chlorine, 2,3,7,8 substituted congeners of dioxin and furan only), TEQ loadings to the lakes appear lower than their actual magnitude. In some cases, the TEQs provided by Ontario decreased by 50% when the contribution of congeners other than 2,3,7,8-TCDD/F was discounted. This suggests that the contribution of 2,3,7,8-substituted dioxin and furan congeners, other than the tetra form, may have a significant impact on effluent TEQ estimates. This result differs from the conclusion which was drawn from the joint *U.S. EPA/Paper Industry Cooperative Dioxin Study - "The 104 Mills Study"* (1990). This report analyzed 10 bleached pulps, 9 wastewater sludges and 9 final wastewater effluents. The U.S. EPA concluded that "even with the most conservative assumptions, that 2,3,7,8-TCDD and 2,3,7,8-TCDF account for the vast majority of the 2,3,7,8-TEC (Toxic Equivalent Concentrations) in each sample."

It must be noted that Table 1 does not represent the output of a single initiative or program to determine the toxic contributions associated with dioxin and furan discharges from pulp and paper mills using chlorine-containing compounds. Rather, it is a compilation of data from various sources offered in a very broad context. The intent behind its inclusions is to provide a preliminary estimate of these discharges and thus encourage the preparation of more precise, tightly constrained and specific tabulation of such data in the near future.

Dioxin is extremely toxic and lethal to some test animals at low concentrations. Studies conducted on rainbow trout suggest that TCDD and TCDF can cause mortality, reduced growth and abnormal behaviour during the fish's early life stages. The 56-day LC50 of 2,3,7,8-TCDD for rainbow trout was measured at 0.046 ppt (part per trillion) and the lowest concentration tested, 0.038 ppt, displayed some effects of chronic toxicity by affecting growth (Bonsor et al. 1988).

Dioxins are sparingly soluble in water, persistent in soils and sediment, and readily bioaccumulated in fish. Once sorbed to soil particles, the main transport mechanisms for these compounds appear to be through erosion and the aquatic transport of sediments. The only environmentally significant path of destruction for dioxins and furans is photodechlorination, a process requiring the presence of another material capable of donating hydrogen atoms (Bonsor et al. 1988). Such a process can occur under the extreme thermal oxidation conditions present during incineration.

Recent technological steps taken by the pulp and paper industry have significantly reduced the discharge of dioxin in wastewater streams. Most significantly new technologies, particularly those which utilize hydrogen peroxide, ozone, oxygen, and/or chlorine dioxide substitution, are replacing elemental chlorine bleaching processes (Business and the Environment 1995); the non-chlorinated processes should eliminate production of dioxin in the process entirely.

Mixed-Function Oxygenase (MFO) Induction Testing

Recently the effect of pulp mill effluent on the **mixed-function oxygenase** (MFO) enzyme system in fish has come under close scrutiny, particularly by the Canadian Departments of the Environment and Fisheries and Oceans. The MFO enzyme system is a key detoxification process in fish, which operates on the smooth endoplasmic reticulum in hepatocytes (liver cells). This general term refers to the function of all hepatic detoxification enzymes collectively. Through MFO action, potentially harmful compounds that enter the body are structurally altered, thereby making it possible for the kidney to remove them. The reaction responsible for this change is known as hydroxylation and involves the addition of an OH- group to the compound, rendering it water soluble. In many cases this is an effective mechanism for the removal of anthropogenic substances from the body without harm. There is, however, the possibility that the conversion may also lead to the formation of an active or more dangerous form of the substance (as is the case in many cancers) or that the water solubility of the substance may allow it to rapidly cross biological membranes and cause more immediate, or acute, complications (Becker and Deamer, 1991).

Under normal conditions, the MFO system operates continuously. Activity level fluctuates depending on such environmental and physiological factors as seasonal temperature and reproductive state of the individuals (i.e. spawning) (Jimenez et al. 1990, in McCarthy and Shugart). Variation has also been discovered between the two sexes and members of various species (Munkittrick et al. 1994).

Researchers have found, however, that fish within an area of pulp mill effluent outflow may exhibit increased MFO activity, possibly as much as 20 times greater than normally expected (Munkittrick et al. 1992). This is attributed to the increased influx of potentially dangerous chemicals that the body must attempt to remove to maintain normal function. To exemplify this, Munkittrick et al. (1992) conducted a study before and after a mill maintenance shutdown, paying particular attention to MFO levels. A significant decrease in MFO activity following the halt of effluent outflow was noted, indicating the stress on the population had been removed. The enzyme system could operate at a lower level as it did not need to compensate for the excess chemical substance which was introduced by the effluent. No direct consequence of elevated MFO enzyme induction has been conclusively determined (Munkittrick et al. 1994); however, Okey (1990) suggested a possible correlation between increased MFO induction and reproductive abnormalities found in fish populations.

A specific MFO enzyme called **7-ethoxyresorufin-O-deethylase** (EROD) is often measured as an overall estimate of the MFO induction level. A study conducted on the Spanish River in Ontario by Servos et al. (1992) found increased EROD induction in white suckers downstream of the effluent outflow from a modernized bleach process pulp mill (i.e. chlorine dioxide substitution, oxygen delignification). Comparatively, the upstream reference sites showed significantly lower levels of EROD activity. This indicates that a factor in the effluent is placing a chemical stress on the population, thereby initiating detoxification mechanisms. Munkittrick et al. (1992), in their pre- and post-mill shutdown study, found no sign of EROD induction during the shutdown, although significant induction had been observed prior to plant shutdown. Interestingly, although the specific effluent component responsible for the induction of EROD activity has not been identified, research has shown no correlation between the level of EROD induction and the sum parameter AOX (Swanson et al. 1992). Munkittrick et al. (1994) supported this conclusion with their observation that EROD induction in white suckers occurred downstream of effluent outflow from both bleaching and non-bleaching facilities.

MFO induction provides a sentinel, early warning indication that a stress has been placed on a population; however, because no single component or components of mill effluent has been identified as the causative agent(s) of this stress, it is impossible to determine what technical modifications are necessary in the pulping/bleaching processes to curtail it. Specifically, it is difficult to gauge the success of abatement programs, including installation of secondary treatment, based on MFO induction levels. The characteristics of the stressing chemical, primarily its degree of hydrophobicity (desire to leave the water stage), further obscure its identification.

Ultimately, the causative agent(s) may be either hydrophillic (water soluble) or hydrophobic (water repelling). Hydrophillic compounds may be quickly released from the organism, therefore demonstrating a rapid reduction in the MFO level if discharges cease. Conversely, a hydrophobic chemical stressor is not easily depurated once it has entered the fish. Therefore, even if treatment or process changes are successful in restricting such discharges, the MFO system may still exhibit elevated levels for some time. Effluent components may sorb to adjacent sediment and exhibit long-lasting effects even after their discharge is ceased. There is a strong possibility that a hydrophobic chemical agent could yield a "false negative," i.e. it could appear that treatment or process changes were not successful in removing the responsible substance, although it had in fact done so.

A study conducted at Jackfish Bay, Ontario by Munkittrick et al. (1992), before and after the installation of secondary effluent treatment, exemplified the difficulties involved in characterizing the causative agent. Following two years of secondary treatment operation, no net reduction in MFO activity was apparent in the population. Assuming a single agent (or single family of compounds) was the causative agent, this finding initially suggested that the stressor was hydrophobic in nature and a sediment store was responsible for the maintenance of high levels. However, the same population demonstrated normal MFO levels after a plant shutdown, indicating that the compound may well be hydrophillic and that secondary treatment had been ineffective in removing the stressor. Until such time as the stressing agent is identified, the complexity of effluent chemical mixtures allows only for limited conclusions.

Although nonspecific, MFO induction appears to have value in determining the potential harm attributable to pulp mill effluent. Determination of a more specific agent and assessment of the relative impact and significance of this stress is necessary to determine what corrective or rehabilitative steps may be required to improve the health of the system.

1.2.4 Pulping and Bleaching Technology

The components of pulp mill effluent, and subsequently the toxicity of the mixture, is related to the pulping and bleaching mechanism employed by the facility. Figure 2 provides a skeleton of the pulp and paper process.

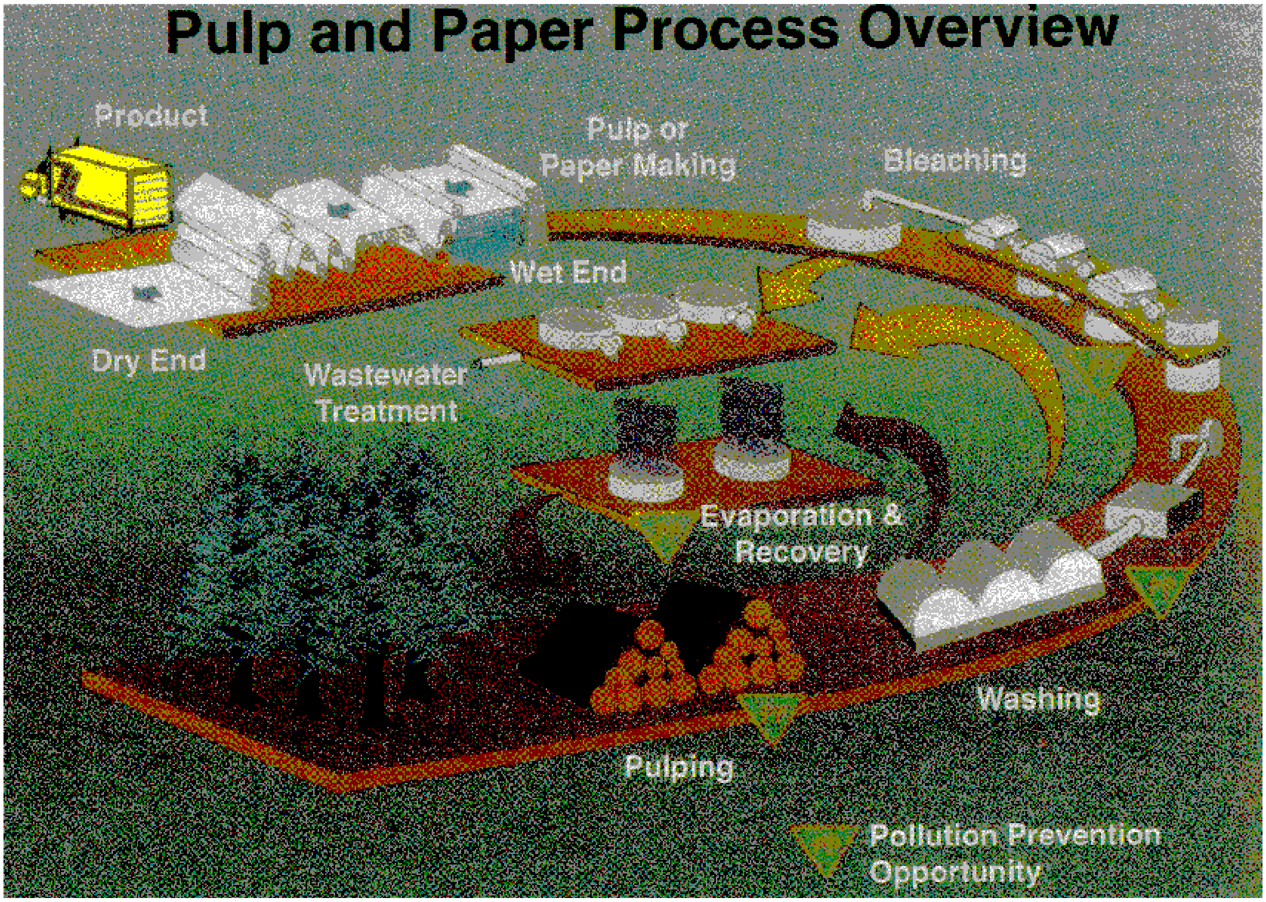


Figure 2. Pulp and Paper Process Overview (Source: Office of Water, U.S. EPA)

Pulping Technology

In general, the objective of the pulping process is to separate the desirable cellulose fibres from other wood components such as lignin and hemicellulose. Hemicellulose surrounds the cellulose fibres, intruding into their pores like a glue between the cellulose and overlaying layer, lignin. Lignin is a complex molecule which surrounds and strengthens the cellulose-hemicellulose structure. Its degradation results in the release of phenol-based compounds, one of the toxic constituents in effluent.

Pulping, which is preceded by mechanical or chemical debarking, cleaning and chipping of the timber (Kringstad and Lindstrom, 1984), may be completed by means of a kraft, mechanical, chemimechanical, thermomechanical or chemithermomechanical process.

Kraft Pulping

Kraft mills employ chemical processes to detach cellulose fibres and dissolve lignin. Wood chips are initially steamed to heat the fragments and fill internal air spaces with water vapour. Kraft pulping liquor, composed of sodium hydroxide (NaOH) and sodium sulfide (Na2S), cleaves ether bonds in the lignin (Kringstad and Lindstrom, 1984), resulting in its degradation during the cooking process. Following this, the application of air under pressure is used to fully separate chips into fibres (Tappi Press 1993).

Mechanical Pulping

Mechanical groundwood pulping physically breaks down the wood to a fibrous state via grinding and chopping. Roughly 90% of wood introduced into the systems becomes part of the resultant pulp. Due to the intense physical conditions, mechanical breakdown of the wood often damages a portion of the cellulose fibres (Madore 1992).

Chemi or Thermomechanical Pulping

Chemi or thermomechanical plants use the manipulation of either chemical or thermal, and mechanical factors to maximize the amount of cellulose released from wood. Some facilities utilize chemical, thermal and mechanical factors throughout their processes. These are referred to as chemithermomechanical plants.

Bleaching Technology

Following pulping, whether by chemical, mechanical or chemithermomechanical means, the pulp fibres are often bleached to meet consumer fine-paper brightness demands.

Entering the bleaching stage, between 5-10% of the original lignin remains (Bonsor et. al. 1988). Because of its natural colour, which subsequently darkens over time, the lignin must be decoloured to ensure prolonged paper strength, stability and brightness. Delignifiers, such as oxygen and chlorine, may be used to further degrade the lignin in unbleached pulp without damaging the cellulose structure (Bettis 1991, in Patrick). This results in a significant increase in paper whiteness and strength; however, quantifiable levels of persistent and bioaccumulative chlorinated organic compounds may be detected after the use of specific bleaching techniques.

Elemental Chlorine

Although common in the past, the use of molecular chlorine bleaching has significantly decreased with the onset of governmental regulations and environmental concerns over the possible adverse effects of dioxins and furans. The detection of dioxins and furans in effluent streams fostered the use of alternate technologies that utilize chlorine dioxide, oxygen, or hydrogen peroxide bleaching.

Chlorine Dioxide

Substitution of chlorine dioxide for molecular chlorine has occurred in many pulp bleaching facilities, both in Canada and the United States. Varying degrees of substitution have been reached, although numerous facilities have moved towards, or achieved, 100% chlorine dioxide substitution. Chlorine dioxide operations require less bleaching solvent to degrade the lignin than do elemental chlorine facilities, and also reduce the generation of harmful bioaccumulative organochlorines.

Oxygen Delignification

Oxygen delignification requires oxygen gas, sodium hydroxide, high pressure and high temperatures. It is most effective as a supplementary stage before chlorine or chloride dioxide bleaching operations. Approximately half the normal amount of bleaching chlorine is needed when oxygen delignification is incorporated.

Hydrogen Peroxide

Rather than undergo chlorine bleaching, mechanically and chemically generated pulps are often treated with hydrogen peroxide (Brooks et al. 1994; ChemInfo 1994). This bleaching method produces a high quality, bright product (Strunk 1991, in Patrick) acceptable by consumer standards.

Ozone

Ozone bleaching may be used as an alternative to hydrogen peroxide, although it must be preceded by oxygen delignification. Oxygen gas is recovered in a gas recycling system, and that which is not completely expended during this process may be transferred back into the oxygen delignification procedure for reuse (Shackford 1991, in Patrick).

1.2.5 Implementing Technology to Meet Present and Anticipated Environmental Regulations

Many companies in the pulp and paper industry have developed technology to meet the requirements of present and future environmental standards. "Anticipation of the extent, rather than the direction of future environmental regulations, has been a major driving force behind novel chemical pulping technologies during the past 10 years" (Lora and Pye, 1995). With the establishment of secondary treatment throughout the basin, engineers and designers have re-evaluated operations and established new technologies that should address environmental concerns while maintaining suitable product quality. Most existing facilities have moved towards **Elemental Chlorine Free** (ECF) and **Totally Chlorine Free** (TCF) bleaching processes, while others have chosen to confront the development of an **Effluent Free Mill** (EFM) or **Totally Effluent Free** (TEF) mill.

Elemental Chlorine Free (ECF) Bleaching

ECF technology is employed primarily by existing facilities upgrading to meet environmental standards. It is generally accepted that the designers of new mills will be looking beyond ECF processes, towards TCF or EFM standards. The use of **chlorine dioxide** (ClO_2) in place of **elemental chlorine** (Cl_2) in the bleaching process is perhaps the most well established mechanism to reduce the quantity of chlorinated organics released in mill effluent. Because chlorinated organic compounds (AOX) formation is directly proportional to the consumption of elemental chlorine, the substitution of ClO_2 for Cl_2 decreases the amount of available reactive chlorine, and therefore the AOX quantity generated (Graves et al. 1993). Used alone, 100% chlorine dioxide substitution resulted in an 80% decrease in total AOX, a 42% reduction in BOD, 62% less generated colour and a 60% decrease in toxicity (Graves et al. 1993).

The **Bleach Filtrate Recycle** (BFR) Process, developed by Champion International, uses chlorine dioxide bleaching in addition to the recovery of chlorine filtrates through the use of a conventional kraft recovery system (Canovas and Maples, 1995). An 86% decrease in AOX release, and 72% reduction in effluent BOD are a result of this recovery process, with approximately 91% of all AOX generated in brownstock washing destroyed before it reaches the recovery boiler (Canovas and Maples, 1995).

Other innovative technology includes oxygen delignification, or oxygen prebleaching, which occurs during the pulping portion of the process. Converting the glue-like lignin into a soluble compound, it reduces the need for chemical treatments for the same purpose. Its role in the reduction in AOX results from its removal of organics that would have otherwise been able to participate in chlorine substitution reactions (Dence and Annergren, 1979). Alone, oxygen delignification has been found to reduce AOX by 41% (Graves et al. 1993), however its combination with other technological advances has been found by Swedish mills to reduce AOX while increasing the efficiency of the mill process (Meadows 1995a).

Outside actual substitution efforts, Alcell Technologies Inc. has developed an "organosolv" process to modify raw pulp to a form that has increased bleachability and increased sensitivity to oxygen delignification (Lora and Pye, 1995).

Totally Chlorine Free (TCF) Bleaching

Albert (1994a) reflects the sentiment of many industrial officials, stating, "It is no longer a question of whether a totally chlorine free process will replace chlorine-based bleaching as the dominant bleaching technology. The only unknown is when will this happen and what will be the rate of change." This is echoed by Lora and Pye (1995), who consider uncertain future environmental regulations, customer requirements, and the concerns of suppliers of risk capital to be the driving forces behind the incorporation of the latest TCF bleaching process into new kraft mill design.

Bleaching, lacking chlorine in any form, may involve the use of such alternate compounds as **hydrogen peroxide** (H_2O_2), **ozone** (O_3), or **peracids**. Hydrogen peroxide bleaching is, however, more expensive than an ECF (chlorine dioxide substitution) process, costing an additional U.S. $26-29 per **air dried metric ton** (a.d. ton). These additional costs incurred throughout the entire process (i.e. generation of materials) are offset to some extent by a $5/a.d. ton savings as a result of decreased chemical makeup costs (Brooks et al. 1994). The benefits gained from process changes, safer operations, decreased corrosion of equipment, decreased environmental impact, the competitive advantage of integrating TCF technology, and the advanced preparation for possible future environmental regulations will result in benefits not considered in the study.

The use of ozone bleaching, in conjunction with hydrogen peroxide bleaching, could result in a net savings of $3/a.d. ton (Brooks et al. 1994), thus narrowing this difference to some extent. Ozone has also been utilized independently, with the first ozone bleaching mill operating successfully in Sweden (Meadows 1995b). Internationally, there are eight ozone-bleaching pulp mills, of which seven are TCF (Albert 1994a).

Because conversion to ozone bleaching is initially an expensive capital venture, the use of peracids is being investigated. Although several limitations in the use of peracids have been identified (e.g. the necessity to carefully regulate pH, poor selectivity, expensive on-site generation and associated safety problems), it has been suggested as a viable intermediate or transition technology. Companies wishing to postpone significant capital spending may use peracid bleaching until TCF technology development has been further advanced (Ricketts 1995).

Effluent Free Mill (EFM)

The fundamentals of pollution prevention suggest that an effluent free mill will undoubtedly be the future goal for this industry in the developed world. Strategists agree that the development of EFMs will not be limited by technology so much as on economics and management techniques. "Closed-cycle mills, by the year 2000, will not be unduly technologically constrained, but rather will be limited by more organizational factors and business needs" (Patrick et al. 1994). The technology, according to Albert (1994b), already exists for the establishment of EFMs and has, in fact, been successfully implemented at such facilities as Louisiana-Pacific Canada's Chetwynd mill in Chetwynd, British Colombia (Young 1994), and Millar Western Pulp Ltd.'s Meadow Lake Mill in Beaver River, Saskatchewan (Fosberg and Sweet, 1994).

The foundation of a **zero effluent mill** (ZEM) rests on an efficient recovery system. Current recovery systems primarily utilize evaporation, although crystallization technology may possess future potential (Kohler 1994). Integration of evaporation with several non-chlorine pulping techniques may lead to the successful development of a zero effluent bleached kraft mill (Albert 1994b).

The Meadow Lake Mill in Saskatchewan, a TCF system, utilizes hydrogen peroxide in its bleaching process. Vapor compression evaporators serve as its water recovery system. Water use, as compared to a conventional bleached chemithermomechanical pulp mill, is reduced from 568 m^3/hr to 68 m^3/hr, an eight-fold decrease. The efficient recovery of water results in a net reuse of 391 m3/hr out of the total 400 m3/hr of effluent sent to the system. Solid waste, which is collected from the effluent, is burned in the boiler. The smelt is then cast into ingots and stored onsite for future chemical recovery (Fosberg and Sweet, 1994). The result is zero liquid effluent release to the environment.

Presently, mechanical vapor recompression evaporators (similar to those at Meadow Lake Mill) are used at the Chetwynd, British Colombia facility, although the plant began its zero effluent operation with the process of freeze crystallization. Three problems prompted the conversion: the crystals were difficult to separate from the effluent until an additional mechanical component was installed; tubes often became clogged with ice due to the increased rate of heat transfer and subsequent degradation in crystal size; and finally, the presence of carbon dioxide aided in the unexpected and unwanted precipitation of calcium carbonate in the crystallizer tubes (Young 1994).

Although no pioneer bleached kraft EFM exists, Albert (1994b) speculates that current technology will provide the framework for its development. A model mill would incorporate evaporization, recovery and oxygen delignification in its processes. A cost assessment revealed that a TCF-EFM (effluent free, totally chlorine free) bleached kraft operation would cost $40 million less than a new ECF bleached kraft mill. In addition, once the capital expenditure has been made, the mill will produce pulp at a cost of $35/ton less than a bleached kraft facility producing paper of a similar quality and strength (Albert 1994b).

1.2.6 Discharges - Performance and Improvements

Updated information on compliance, both in the U.S. and Canada, is needed to provide an accurate picture of progress towards the regulatory requirements. Table 2 is current as of 1992 data, the most recent basinwide data available for U.S. and Canadian sources through the U.S. EPA Permit Compliance System. It does not reflect the significant reductions that have occurred or will occur by the end of 1995, when all Canadian mills should have secondary effluent treatment or equivalent in place.

1.2.7 Findings

- The focus on the industry had shifted from control of BOD (biochemical oxygen demand), TSS (total suspended solids) and acute toxicity to the tracking of dioxin, dibenzofurans and AOX (adsorbable organic halogens) and now to pursuit of biomarkers such as sublethal reproductive impacts, stimulation of liver enzymes (EROD) and a search for more such indicators. These developments parallel the Commission explorations of the past several years.
- These latter phenomena appear to be stimulated by the pulping process generally and do not appear confined to the bleached kraft mills. Attribution of cause, including identification of a particular causative agent or contaminant, continues to be problematic.
- Notwithstanding this evolutionary process, the above indicators retain some relevance in the pulp-producing countries.
- As advocated by the Water Quality Board in the early and mid 1980s, the industry in the Great Lakes basin has largely completed a transition to secondary effluent treatment and use of chlorine dioxide rather than chlorine gas in bleaching. Effluent acute toxicity effects have been largely eliminated and dioxin in effluent has been substantially reduced.
- The alteration in bleaching technology indicates that this industry is applying a pollution prevention rather than a pollution control approach. This former approach will be further reflected in other process changes, including use of ozone and hydrogen peroxide in bleaching, closed bleaching cycles, oxygen delignification and, ultimately, the **Totally Effluent Free** (TEF) mill.
- The Government of Canada has entered into a five-year joint venture with the industry to investigate closed mill technology. Swedish industry appears to be moving in this direction as well. Total waste management, particularly that in gaseous or solid form, must be carefully considered in the Total Effluent Free mill.
- There is a need to move to 'integrated monitoring,' 'biomarkers,' 'bioindicators' and similar environmental tracking devices. While some have been developed, their evolution to routine application will be a significant challenge.

1.2.8 Recommendation

Given the evolution in the pulp and paper sector from pollution control toward pollution prevention, from conventional single indicators of effluent quality to consideration of more complex bioindicators in adjacent ecosystems, the move by some regulators to a multi-media cluster approach, the extent of ongoing research into bioindicators and emerging technologies, and concerns over the sustainability of the forestry, the Parties should prepare a joint report under SOLEC further delineating the status and direction of this industrial sector.

1.3 Row-Crop Pesticides and Related Agricultural Issues

1.3.1 Background

The Great Lakes basin is among the most intensively cultivated areas in North America and, as such, receives significant applications of pesticides. In its 1983 report to the Commission, the **Great Lakes Water Quality Board** (WQB) examined the issue of controlling nonpoint source pollution, including that from pesticides, and concluded that one of the most appropriate management tools was reduced tillage practices (conservation tillage, including no-till).

In 1986-87, the Water Quality Board completed an initial assessment of urban and rural pesticide usage in the Great Lakes basin (WQB 1987). It determined that the highest agricultural applications were in counties adjacent to Lake Erie where corn and soybeans are the principal crops. In the same report, the Board indicated that non-agricultural applications of certain pesticides, particularly in or near urban areas, exceeded the per-acre agricultural applications. Since the completion of this earlier WQB work, much of the attention in regard to agricultural pesticide usage has further shifted from the historically used pesticides such as DDT to current use herbicides, particularly the triazines.

Row-crop pesticide applications were examined on the U.S. portion of the Great Lakes basin for 1991 and 1993. Pesticides applied to corn and soybeans on the U.S. side totalled more than 11 million kilograms of **active ingredient** (A.I.) for 1991 and close to 10 million kilograms of A.I. for 1993. Commission staff also assembled data on row-crop pesticide applications on a county-by-county basis with a particular emphasis on the Lake Erie basin. These data were then entered into a geographic information system. Figures 3, 4 and 5 show the 1993 pesticide usage in the Great Lakes basin for corn, soybeans and the summation of corn and soybeans, respectively. These data confirm that selected counties in the Lake Erie basin are among the highest in the Great Lakes basin in pesticide usage for these crops.

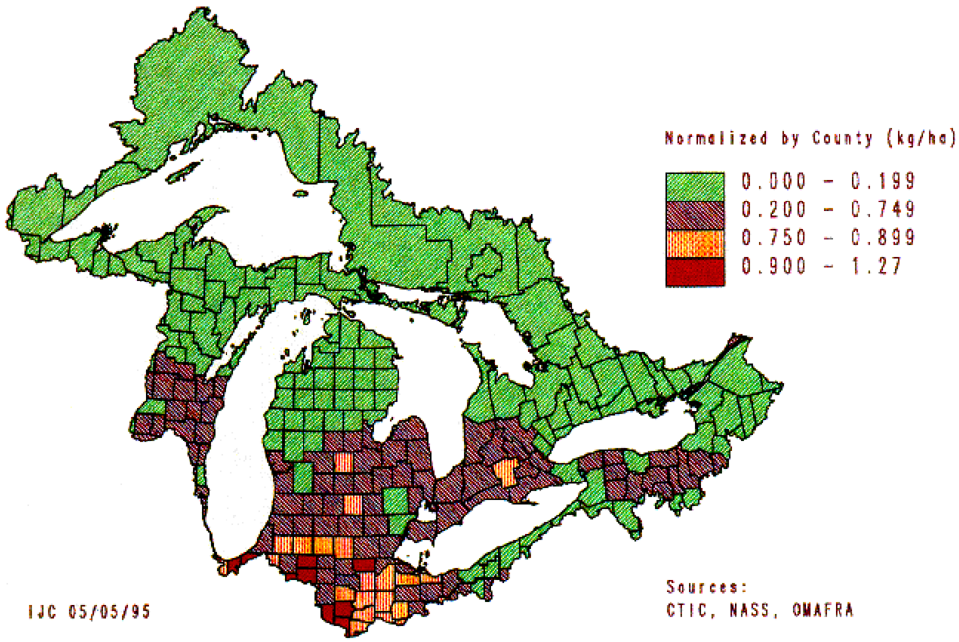


Figure 3.

1993 Pesticide Usage for Corn

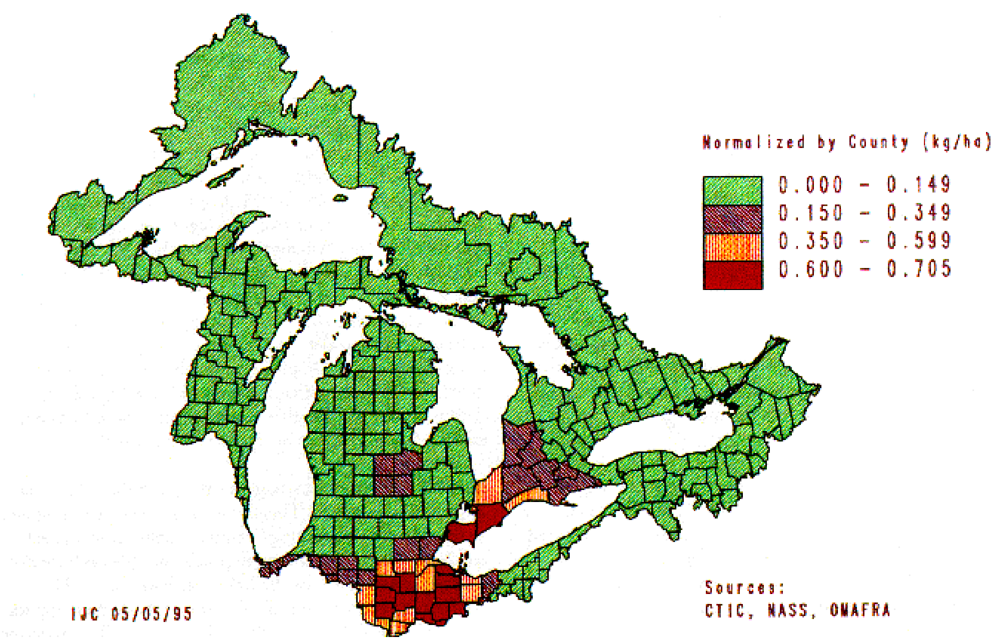


Figure 4.

1993 Pesticide Usage for Soybeans

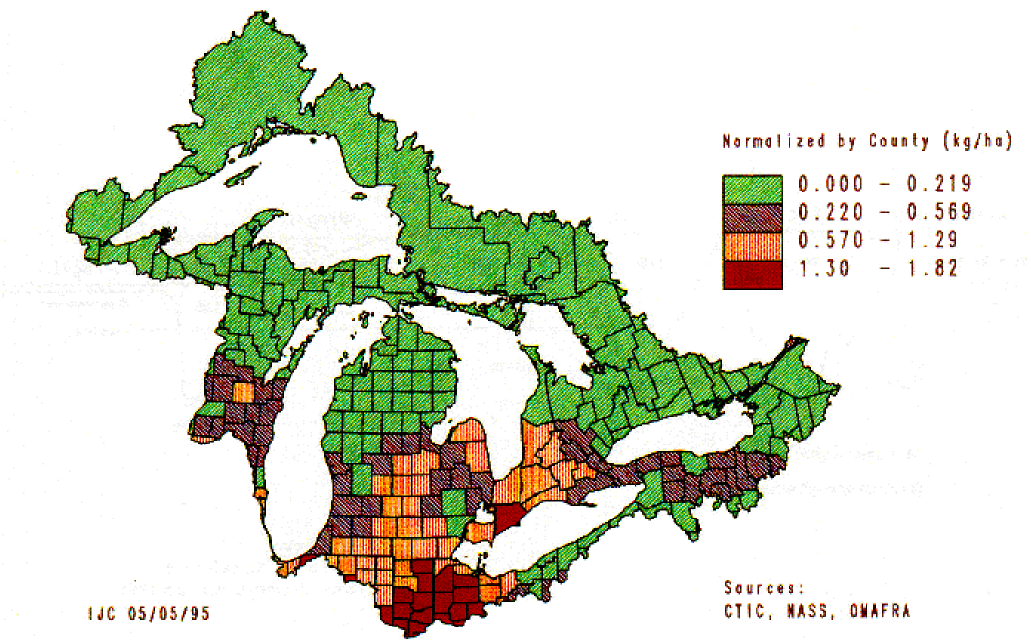


Figure 5.

1993 Pesticide Usage for Corn and Soybeans

The applications of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) were of particular interest, due to its known occurrence in Lake Erie tributaries used as public drinking water supplies.

Until recently, little data were available on the occurrence of atrazine in open lake waters. A first estimate of total atrazine and the transformation product **desethylatrazine** (DEA) was 68 metric tons for the waters of Lake Erie in 1993; the concentration of atrazine in open lake waters for the same year was 75 ng/L and 93 ng/L for the western basin and eastern basin of Lake Erie, respectively (Schottler and Eisenreich, 1994). The concentrations of DEA in 1993 for the western basin and eastern basin were 47 and 67 ng/L, respectively. Schottler and Eisenreich (1994) concluded that (A)trazine is well mixed both vertically and laterally in the lakes, indicating that the water column residence times must be long, with half-lives on the order of months to years.

In fact, their estimates of the half-life for atrazine ranged from five months in the western basin of Lake Erie to as long as 10 years for Lake Michigan. Accordingly, as defined by the Great Lakes Water Quality Agreement, atrazine is one of the few agricultural pesticides which could, on the basis of estimated half-life in the environment, be considered a persistent toxic substance.

Atrazine concentration levels have been examined elsewhere in the Great Lakes Basin Ecosystem. An estimate of atrazine concentration and inventory for each of the Great Lakes is displayed in Figure 6. An approximation of atrazine concentration for the St. Lawrence River is also displayed in Figure 6. Average annual concentrations in the St. Lawrence River were 10.4 and 3.4 ng/L in 1990 and 1991, respectively (Lemieux, Quemerais and Lum, 1995). The draft Lakewide Management Plan for Lake Michigan (U.S. EPA 1993) lists atrazine as an emerging pollutant, defined as one which has the potential to impact the physical or biological integrity of Lake Michigan. Schottler and Eisenreich (1994) estimated the total inventory of atrazine and DEA for Lake Michigan waters to be 275 metric tons in 1993, and the concentration of atrazine and DEA in open lake waters for the same year were 37 and 24 ng/L, respectively. The draft LaMP recommends that such emerging pollutants be considered as priorities for data gathering and research activities. Despite a shorter half-life in Lake Erie, due to the greater application rates and relative lack of stream buffers in Lake Erie basin, atrazine should be considered a critical pollutant for the Lake Erie LaMP.

Atrazine applications throughout the basin for 1993 were 2,770,000 kilograms. This herbicide has been documented as an endocrine-disrupting chemical (Colborn, vom Saal and Soto, 1993) and, although precise use figures have not yet been determined for the Lake Erie basin for 1993, atrazine can be expected to have among the highest applications by weight of all agricultural pesticides. The endocrine disrupting potential of this herbicide is of most concern in the western basin of Lake Erie, due to the elevated levels of another known endocrine disruptor - polychlorinated biphenyls - also present in that area.

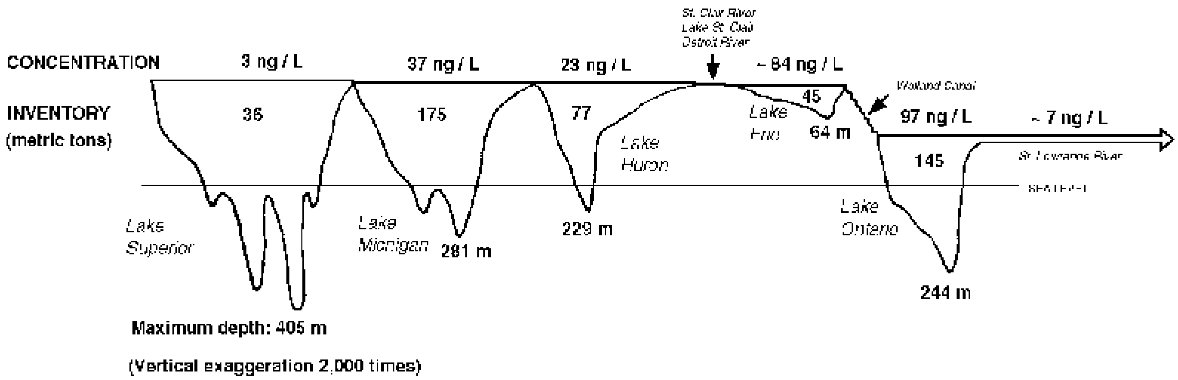


Figure 6.
Atrazine in the Great Lakes
Modified from:
Schottler and Eisenreich 1994
Lemieux, Quémerais and Lum 1995

1.3.2 Board Activities under the 1993-95 Lake Erie Priority

As part of their execution of the Lake Erie priority, the Water Quality Board sponsored two workshops on Pesticides and Related Issues in Toledo Ohio, on August 30, 1994 and on March 27 and 28, 1995. Farmers, representatives of government agricultural and environmental agencies, academics, and representatives of public interest groups and pesticide producers were in attendance. Drawing upon the earlier Commission focus on conservation tillage practices and pesticide applications, the workshops considered broad methodologies designed to affect significant reductions in pesticides in Lake Erie and the Maumee River.

Ontario's Food Systems 2002 initiative was among the programs reviewed. The Ministry target is a 50% reduction in pesticide applications by 2002. The program goals are: i) preserve and augment beneficial species; ii) consider the economic threshold for the use of alternatives to pesticide applications; iii) examine the preventive approach to pest control versus the corrective one, largely realized through pesticide application; iv) reduce impacts on the environment; and v) address health and social issues while arriving at sustainability. As a result of several factors, including the emerging pesticide resistance among key species, **Integrated Pest Management** (IPM) was advanced as a cornerstone of the program.

One definition of IPM, drawn from the June 1990 report on this subject by the Science Advisory Board, is "the optimization of pest control in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazard to humans, animals, plants and the environment" (Dover 1985).

The program has three pillars. The first is **education**, including training applicators through a mandatory certification program (a course for vendors is also offered). **Research**, largely supported through the Agricultural Research Institute of Ontario (95 projects), is another. Criteria for funding include consideration of nonchemical alternatives, examinations of efficiency of application technology, and a systems approach to pest control.

Finally, **field delivery** has been assigned to 15 management advisors responsible for fruits and vegetables, both field and greenhouse crops. Twenty-two commodities are covered under an IPM program, and a pest management hotline has been established. A major component is development of Environmental Farm Plans by individual growers, with a target of 5,000 completed plans by the end of 1994. Other responsibilities undertaken included pesticide collection, disposal and recycling, a Vegetation Management Advisory Program, Pest Diagnostic Advisory Clinic, and Turfgrass Nursery IPM Initiatives.

According to the most recent Ontario Pesticide Survey, since 1987 application of pesticide active ingredient has been reduced by 17%; a 40% reduction in applications to corn appears within reach and a fifty percent (50%) reduction to potato crops has been realized along with an 80% reduction in use on greenhouse floriculture.

Some identified ongoing concerns include: i) too narrow a focus, in that programs are still pesticide driven; ii) a lack of uniform standards/thresholds and methodology; iii) few pesticides are developed with IPM in mind; iv) a need to improve management of the introduction of new cultivars into a complex; v) the dominance of food appearance as a consideration; vi) a need for more education and delivery; and vii) erosion of the research effort due to a lack of long-term commitment. To 1992, the Ministry has carried 85% of the cost of these programs; they now fund only one-half of the program. Firm support for the balance had not yet been identified.

Representatives of the pesticide manufacturers reviewed their involvement in no-till demonstration tours; crop residue management conferences; preparing educational materials and encouraging conservation practices, including the development of buffer zones in fields adjacent to streams, rivers and lakes, and development of a "Code of Practice" for pesticide usage. Application education was being addressed through the development of "Codes of Application." "Well assist" programs for the identification and rehabilitation of contaminated farm wells are also being supported, as well as herbicide consultations, genetic engineering efforts and the application of biotechnology to develop better crops.

Further evidence of recent reductions in herbicide loading to the environment, largely as a result of more effective application and results, was offered at the workshop. Although treated acreage remained comparable from 1985 to 1990 in Illinois, the amount of pesticide **Active Ingredient** (AI) applied had decreased. Current instructions for the common herbicide "Roundup" call for half the application previously recommended.

The extent of conservation tillage for stream and river sediment control in a substantial portion of the Lake Erie basin also was reviewed. Sediments were about 50% of all primary river pollutant loadings. The level of conservation tillage applications is estimated at one-third of all cultivated acreage. Under the 1985 U.S. Farm Bill, soil erosion has been reduced by that same fraction.

While it has been suggested that no-till farming uses more pesticides, the impact on the larger environment may not be detrimental in these cases, given improved soil containment. After initial use following introduction of no-till practices, pesticide amounts are typically reduced. Thus, corn yields have levelled or decreased slightly in no-till applications and chemical usage has dropped. IPM was being used and most pesticide applications were now to surface postemergent plants at lower application levels.

Emerging technologies such a biogenetics, global positioning and soil doctoring, which determine the precise field location and fertilizer requirement, were noted as positive developments. Academic researchers examined some of the hormonal imbalances, changes in cell masses, reproduction and growth, and immune and nervous system function in certain species of mammals in response to stressors, including pesticides. Aldicarb, atrazine and nitrate mixes were tested at levels that were present in groundwaters in part of the basin, seeking hormone, endocrine and immune system disruption. "Aggression" behavioral factors were also considered and two- and three-factor interactions showed an impact associated with these chemicals.

A 1986 study on the pesticide 2,4-D demonstrated that effects emerged after only one year. Animals in the wild are subjected to many more stresses; it was suggested that experiments should be performed outdoors, as higher toxicity impacts could be evident under such circumstances. Testing needed to be revised with multiple exposures, more endpoints in addition to cancer, and the use of chemical mixtures and more stressors (disease, nutrition and climate).

Some reduction in growth hormone in the species examined was noted. Impacts on the immune system remained a concern, which should be addressed through a mixture testing approach at groundwater concentrations. Further, while no-till was effective in controlling runoff to surface water bodies, the degree of migration to and impacts on groundwater remained unclear.

A representative of the **World Wildlife Fund** (WWF) outlined that organization's belief that a major initiative to reduce pesticide risk in the Great Lakes basin was appropriate, based on both human health and economic considerations. Endocrine system disruption or modulation and immune system compromise in selected species were particular concerns.

The WWF pesticide application inventory under development considered pesticide sources such as food storage, golf courses and lawns, in addition to traditional agricultural applications. The form and amount of pesticide movement off the lands are well quantified. Categories of pesticides, some of which are persistent and bioaccumulative, were reviewed. Further emphasis was given to those that disrupted the endocrine system, put birds at risk and had other possible undesirable outcomes.

Other identified concerns included: i) the cancer risk in farmers and workers; ii) endangered or imperiled species; and iii) the effect of low doses or single exposures to pesticides on reproduction of various species.

Major issues identified specific to the Maumee basin of Lake Erie included: the desire to reduce pesticide use; questions dealing with risk management; need for an inventory of the extent of no-till and an assessment of its effects through cost-benefit analysis; the registration of biological agents; the environmental objectives of wildlife/animal protection; the need for further local farmer-to-farmer interaction; exploring the basis for determining and achieving a "healthy ecosystem"; accountability for voluntary programs; further assistance in technology transfer; the need to continually account for economics.

There appeared to be a general consensus that the key elements of any future approach to reducing pesticide use and associated loss to the environment would include use of no-till cultivation, integrated pest management, and whole farm planning. There was also a suggestion that water-soluble herbicides associated with corn and soybeans should be further examined; development of a partnership among growers, chemical companies, distributors and consumers, as well as the academic community, was also proposed.

The need for further research to establish baseline reporting systems was evident. Profitable alternatives to pesticides involving chemical and biological IPM, the use of Geopositioning Systems for more accurate pesticide application, as well as variable application rate technology were all discussed.

Education and technology transfer should be encouraged through public access to information, farmer networks for education and the use of professional researchers in an on-farm setting. The agricultural retailer could perform a useful role in IPM education and tracking programs. The coordinated collection of data using a common methodology, and a move to whole farm planning, were also advocated.

Policy changes toward mixed commodity market programs (diversify crops toward hay, for example) and a patent period extension for types of pesticides/herbicides that are more benign were suggested. Development of a market for food grown using some of the available alternatives could increase application of innovative equipment, production and services.

It was suggested that any established goals for pesticide reductions should be realistic (perhaps based on the drinking water standards); economic incentives and technical support should be included in the promotion of such reductions.

1.3.3 Workshop Conclusions/Recommendations

Further research is needed on pesticide application rates and, in some cases, possible subtle endocrine effects. Appropriate reduction targets to safeguard human, wildlife and ecosystem health should be considered for incorporation in appropriate RAPs and LaMPs, particularly those associated with Lake Erie.

Database development and analysis for no-till and pesticide applications should be pursued on a binational basis and the application of geopositioning, remote sensing, biotechnology and other emerging capabilities for further delineation of these issues should be explored.

Effective communication on a farmer-to-farmer basis, including the government agencies, the farm suppliers and manufacturers, and the academic community, should be supported and encouraged.

1.4 Groundwater in the Lake Erie Basin

Annex 16 of the Great Lakes Water Quality Agreement, as amended by Protocol and signed November 18, 1987, states that the Canadian and American governments shall identify, map and control sources of groundwater contamination affecting the Great Lakes. The Water Quality Board completed a literature review to evaluate scientific knowledge concerning the role of groundwater in shaping Lake Erie water quality. Tile drainage of cultivated areas was considered within the context of this review, as tile drains are considered to be conduits for groundwater to surface water bodies.

The qualitative and quantitative contribution of groundwater to Lake Erie is poorly defined in the scientific literature. Current data gaps include mapping hydraulic potential in Lake Erie bottom sediment, estimating near-shore and offshore groundwater flux, determining the extent and significance of subsurface geologic heterogeneities (including faults) in the Lake Erie basin, and quantifying the extent of chemical loading via groundwater.

The topography of Lake Erie divides into three distinct regions. West of Pelee Island is a shallow basin that averages 7.3 meters (24 feet) in depth. A broad, flat-bottomed central region, averaging 18.3 meters (60 feet) in depth, extends from Pelee Island to a sand and gravel ridge that transects the lake from Long Point, Ontario to Erie County, Pennsylvania. The eastern basin, extending from Long Point to the Niagara River, is the deepest portion of the lake, averaging 24.5 meters (80 feet). Composition of bottom material is highly variable, ranging from silt and organic detritus to sand, gravel and exposed bedrock. A layer of compacted glacial till is also present and appears to be spatially variable.

The bedrock geology of the Lake Erie basin is dominated by sedimentary rock of Devonian and Silurian age. These limestones, dolomites and shales typically exhibit extensive fracturing. An example of a major regional structure is the Bowling Green Fault which runs north-south through the carbonate bedrock of northern Ohio.

Overlying the bedrock of the Lake Erie basin are till, glacio-fluvial and lacustrine sediments, beach ridge deposits, and/or glacial land forms such as moraines, drumlins and kames. The till and lacustrine deposits are clay rich, exhibiting variable hydraulic conductivities, or water conductance properties, which change with depth and the extent of fracture development. Conversely, fluvial sediment, beach ridges, and certain moraines are composed of highly permeable sands and gravels, which introduce considerable variability to the Lake Erie hydraulic conductivity profile.

A variety of methods have been employed to obtain hydraulic potential readings in bottom sediments of the Great Lakes. One particularly promising approach involves obtaining electrical conductivity measurements of bottom sediment, which can then be related to the ability of water to pass through these zones. Aside from being relatively cost effective, this method may prove to be more accurate than conventional coring practices.

Variability in soil and sediment hydraulic potential directly impacts groundwater flow patterns and velocity in the Lake Erie basin. Increased tributary base flow, due to highly porous sediments, is evident in the Big Creek, Ontario drainage basin where approximately 43 percent of mean annual flow and 95 percent of summer flow are attributable to groundwater discharge.

Excluding the Detroit River, direct tributary flow to Lake Erie is approximately 2.2×10^{10} m^3 (7.8×10^{11} ft^3) per year. Between 20 and 60 percent of this flow is contributed by groundwater base-flow. Direct groundwater flow to the St. Clair River, Lake St. Clair and Detroit River has been estimated to approximate 7.2×10^{7} m^3 (2.5×10^{9} ft^3) per year. Estimating direct groundwater flux to Lake Erie was not possible due to a lack of adequate and sufficient data. An estimate of 3.6×10^{6} m^3 (1.3×10^{8} ft^3) per year was obtained from the literature, although the model used to obtain this figure solely considered deep groundwater flow through fractured bedrock (not flow through nearshore sediment) and did not fully account for subsurface heterogeneities. Research performed in Lake Michigan, however, indicates that groundwater flow through near-shore sediment significantly exceeds groundwater flow through offshore sediment.

At a local level, perched aquifers form within sand and gravel deposits that are underlain by less permeable glacial till, such as those found in Perry, Ohio. These shallow aquifers are highly susceptible to anthropogenic sources of contamination, such as nitrate and chloride pollution.

Naturally occurring groundwater pollutants in the Lake Erie basin include metals, hydrocarbons, (BTEX or Benzene, Toluene, Ethyl Benzene and Xylenes from petroleum seeps), and chloride. These natural sources are further augmented by inputs from human activity, which together comprise the total chemical loading of these substances to Lake Erie. In the Maumee River basin, groundwater contributes 75 to 95 percent of the background levels of various heavy metals, including chromium, copper, nickel, lead and zinc.

Agricultural pollutants, particularly herbicides and nitrate, are common groundwater pollutants throughout agricultural regions of the Lake Erie basin. Studies concerning mobility and fate of the herbicide atrazine indicate that between 1.0 and 1.5 percent of the total quantity applied to an agricultural site may be discharged to surface waters via tile drainage. A study conducted in Southern Ontario indicated that approximately 50 kg of nitrate per hectare per year (45 lbs N/acre/year) leached to groundwater in a study conducted in southern Ontario, with approximately 10-20 kg N/ha/year (9-18 lbs N/acre/year) discharging to the local stream watershed via groundwater flow. Base flow has been estimated to contribute 25-50 percent of total stream flow nitrate loading in an unglaciated portion of east-central Ohio.

Deep well injection of industrial waste continues to be practiced in Lake Erie basin states including Ohio and Michigan.

1.4.1 Conclusions and Recommendations

Scientific knowledge concerning the role of groundwater in shaping Lake Erie water is incomplete and unintegrated. However, apparently groundwater plays a significant and potentially more important role than surface runoff in directing drainage to Lake Erie and in transporting nitrogen, pesticides, heavy metals and other contaminants to the lake. Estimates of groundwater flow to Lake Erie tributaries range from 20 to 60 percent of total flow. In topographically flat, poorly drained regions, such as the extensive clay plains of southwestern Ontario and western Ohio, baseflow, combined with agricultural tile drain effluent, probably accounts for a major part of tributary flow. Research is required to develop base-flow estimates for individual watersheds within the Lake Erie basin, as well as to assess the implications of anthropogenic groundwater withdrawals and surface water impoundment/diversion practices on base-flow maintenance.

Considerable hydraulic variation exists within bedrock and sediment throughout the Lake Erie basin. The fractured limestone/dolomite bedrock common throughout much of the basin can transmit large quantities of water. Buried valleys, solution channels and other macropores further add to the volume of water discharged. Natural faults and thousands of abandoned oil and gas and water wells add considerable complexity to subsurface flow in the Lake Erie basin. Septic systems at permanent and seasonal dwellings which line Lake Erie and its tributaries are often poorly maintained and are a major source of ground and surface water contamination (Figure 7). Recent evidence suggests that the clay till sediments common throughout the western portion of the Lake Erie basin are more hydraulically conductive than previously believed, due to extensive fracturing.

To date, little progress has been made towards fulfilling Annex 16 of the Great Lakes Water Quality Agreement. Due to a lack of applicable research, the role of groundwater in shaping the water quality of Lake Erie cannot be adequately assessed. Numerous research opportunities exist that would resolve data deficiencies. These include:

- The compilation of existing Lake Erie basin geological, hydrological and hydrogeological research. Such information is fragmented amongst academic institutions and government agencies within the basin.
- Field assessments of Lake Erie bottom sediment hydraulic potential. Identifying subsurface heterogeneities which provide for rapid groundwater flux is a subject of particular urgency. Conducting geoelectrical field survey(s) may prove to be a reliable, cost-effective method to obtain this information.
- Mapping the occurrence of fault systems within the Lake Erie basin and their associated impact on groundwater flow and contaminant transport, especially in and around Areas of Concern.
- Characterizing the chemical composition of groundwater discharging to Lake Erie and to Lake Erie tributaries.

It is important to note that remediation of contaminated aquifers has proven to be an extremely difficult task, judging from experience gained from "Superfund" sites in the U.S. According to Annex 16 of the Great Lakes Water Quality Agreement, the Parties have agreed to "control the sources of contamination and the contaminated groundwater itself" within the Great Lakes basin. The implementation of groundwater protection schemes, such as well-head protection programs, are a matter of urgency throughout the Great Lakes basin.

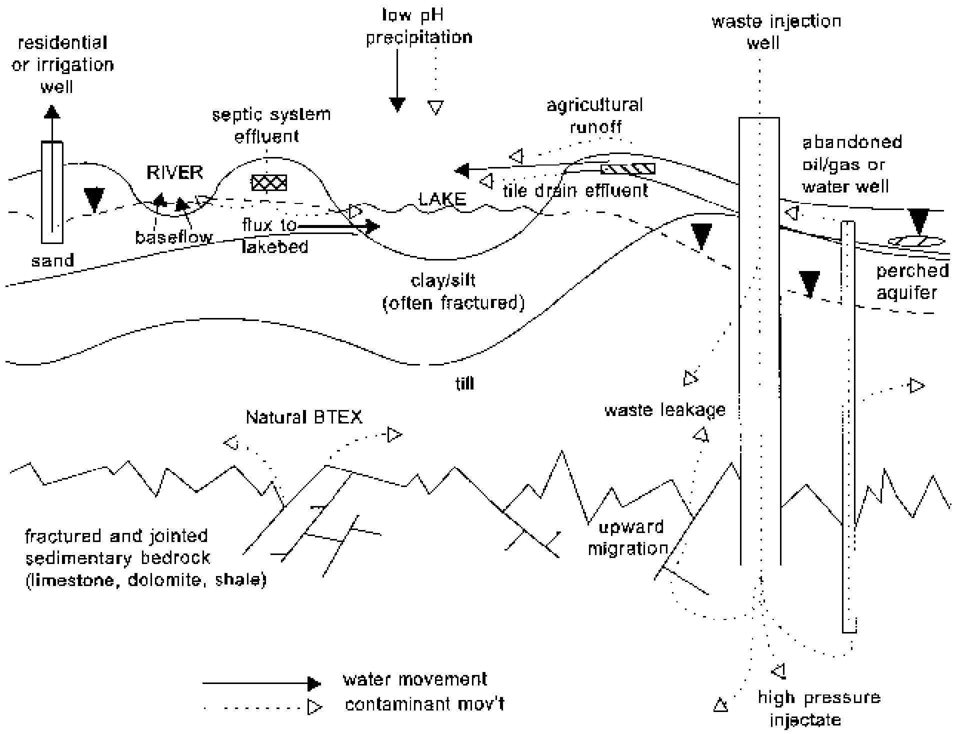


Figure 7.

Schematic Drawing of Some Influences on Groundwater Quality in the Lake Erie Basin

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1.4.2 Water Quality Board Recommendation

The Water Quality Board recommends that:

The Commission should promote the preventive approach in protection of the groundwater resource and encourage the Parties to proactively implement Annex 16 of the Agreement.

1.5 Future Directions

In its comments to the Commission regarding the 1995-97 priorities and beyond, the Board has suggested a focus on the impact of persistent toxic substances on human and ecosystem health in conjunction with the Science Advisory Board. Further, the Board has advocated a review of the Critical Eleven list of persistent toxic substances established by the Board in the mid-1980s, and a further examination of the various pathways for such substances to the lakes, in continental and global contexts.

In support of the continuing evolution of **Remedial Action Plans** (RAPs) and **Lakewide Management Plans** (LaMPs), a review of the application of current, particularly in situ, technology for the remediation of sediments contaminated by persistent toxic substances appears appropriate.

The Board has also expressed an interest in a coordinated review of the status and adequacy of programs to control the access of exotic species, such as the zebra mussel, to the basin.

While the Board cannot clearly define its own possible role, the impact of revised program support and emerging powerful information technologies, such as the Internet, suggest that a review of the state of binational information collection, management and dissemination activities would be appropriate. The contribution of these efforts to effective public education could also be considered.

With regard to the Board's activities under the 1993/95 biennial cycle, the Board felt a further review of pollution prevention efforts in the Basin would be appropriate. It also recognized the Parties' effort in hosting SOLEC (the State of the Lakes Ecosystem Conference) at Dearborn, Michigan in October 1994. A proceedings from this conference was to follow as of mid-1995; it is the Board's understanding that this document is to be formally transmitted to the Commission as part of the Parties' review of progress under the Great Lakes Water Quality Agreement. The Board stands ready to assist the Commission in any appropriate way with the review and consideration of this document and the related process.

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