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

Chapter Three: Council of Great Lakes Research Managers

3.0 COUNCIL OF GREAT LAKES RESEARCH MANAGERS ACTIVITIES

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We can choose to pursue an aim or goal - such as the aim of understanding better the universe in which we live, and ourselves as part of it - which is autonomous of the particular theories or frameworks that we construct to try to meet this aim. And we can choose to set ourselves standards of explanation, and methodological rules, which will help us to achieve our goal and which it is not easy for any theory or framework to satisfy. Of course, we may choose not to do this: we may decide to make our ideas self-reinforcing. We may set ourselves no task other than one we know our present ideas can fulfil. We certainly can choose to do this. But if we do choose to do this, not only will we be turning our backs on the possibility of learning that we are wrong, we will also be turning our backs upon that tradition of critical thought (stemming from the Greeks and from culture clash) which has made us what we are, and which offers us the hope of further self-emancipation through knowledge.

To sum up, frameworks, like languages, may be barriers. They may even be prisons. But a strange conceptual framework, just like a foreign language, is no absolute barrier: we can break into it, just as we can break out of our own framework, our own prison. And just as breaking through a language barrier is difficult but very much worth our while, and likely to repay our efforts not only be widening our intellectual horizon but also by offering us much enjoyment, so it is with breaking through the barrier of a framework. A breakthrough of this kind is a discovery for us. It has often led to a breakthrough in science, and it may do so again.

- Karl R. Popper, *The Myth of the Framework: In defence of science and rationality (1994)*

Chapter Three: Council of Great Lakes Research Managers

Introduction

The **Council of Great Lakes Research Managers** (Council) was established to enhance the ability of the Science Advisory Board to provide leadership, guidance and evaluation of Great Lakes research programs. The new terms of reference issued in 1991 directs the Council to compile a research inventory identifying research needs and to coordinate research projects. In addition to reporting on progress toward achieving our goals, we have expanded our geographical area of interest and membership to include the St. Lawrence River and thus now use the term, Great Lakes-St. Lawrence River Basin Ecosystem. Membership consists of individuals managing and coordinating research programs of federal, state and provincial governments in the United States and Canada, and representatives of private institutions.

3.1 Research Assessment

The Council of Great Lakes Research Managers was set up in 1984 to enhance the ability of the Commission to provide effective leadership, guidance, support and evaluation of Great Lakes research programs with particular reference to programs required or funded pursuant to the provisions of the **Great Lakes Water Quality Agreement** (GLWQA). The membership of the Council is comprised of persons responsible for research programs related to the implementation of the Agreement.

The International Joint Commission requested the Council of Great Lakes Research Managers to prepare an assessment of the adequacy of research relevant to the Great Lakes Water Quality Agreement. In response to this request for advice, the Council has focussed this review on significant developments in research on fish, wildlife and humans exposed to persistent toxic substances in the Great Lakes. In particular, there has been a significant advance in the funding and coordination of research, particularly in the field of human health.

3.1.1 Human Health

United States

In the United States, Congress amended part of the Federal Water Pollution Control Act in 1990 to include the provisions of a Great Lakes Critical Programs Act. Part of that act mandated the **Environmental Protection Agency** (EPA), the **Agency for Toxic Substances and Disease Registry** (ATSDR), and the Great Lakes States to submit a report to Congress by September 1994. The report (Agency for Toxic Substances and Disease Registry, in prep.) was to contain an assessment of the adverse effects of water pollution on the health of people living in the Great Lakes States. Congress authorized annual funding of up to $3 million to support preparation of this report.

The Agency for Toxic Substances and Disease Registry (1994) received $2 million for fiscal year 1992 and $3 million for each of the years 1993 and 1994 to support research studies on the effects of pollutants on human health in the Great Lakes basin. These ATSDR research activities are consistent with the overall mission of ATSDR, which is to prevent adverse health effects and diminished quality of life associated with human exposures to hazardous substances from waste sites, unplanned releases and other sources of pollution present in the environment.

The Council of Great Lakes Research Managers endorses the Great Lakes Health Effects Research Strategy developed by the ATSDR. The goals of this strategy (DeRosa and Johnson, in press) are to identify human populations residing in the Great Lakes basin that may be at greater risk of exposure to chemical contaminants present in one or more of the Great Lakes, and to help prevent any adverse effects. This strategy is built on the following five traditional elements of disease prevention:

- Identification of patterns of morbidity and mortality
- Evaluation of causal factors accountable for the observed pattern of morbidity or mortality
- Control of the factors found or thought to be accountable for the observed morbidity and mortality
- Dissemination of information about the identification, evaluation, and control of the observed pattern of

morbidity and mortality, and
- Infrastructure to support the identification, evaluation, control, and dissemination elements of disease prevention. This strategy has been adopted by the International Joint Commission as a framework for the study of effects of contaminants on human health and on other organisms in the Great Lakes basin.

In fiscal year 1992, ATSDR funded eight epidemiological investigations and a ninth study to develop more sensitive methods to detect persistent contaminants in human biological tissues and fluids. In fiscal year 1993, a tenth grant was added to establish an interlaboratory program for quality control and quality assurance for the other nine research investigations.

The awards fall into two broad categories: environmental and epidemiological studies. The purpose of the environmental studies is to characterize exposure pathways for the pollutants in the basin, with an emphasis on developing some new methods that will permit a more rigorous assessment of the relationship between those pathways and specific body burdens of the toxic substances.

The epidemiologic investigations are to characterize exposure as well as human health outcomes in susceptible populations. They were intended to expand on existing cohort studies to the extent feasible and to assess the potential for subtle forms of toxicity increasingly of concern in the basin, including neurobehavioural, developmental, reproductive and immunotoxic effects, including the potential for transgenerational impacts. The potential for transgenerational effects (including neurobehavioural deficits) is perhaps one of the more challenging problems confronted by health researchers, due to the potential influence of both paternal and maternal exposures that result in adverse health effects.

Of six existing cohorts supported by the awards made to date, three are cohorts of sport anglers in the states of Michigan, New York and Wisconsin; two represent cohorts of Native American Indians, the Mohawk Indian and the Red Cliff Indian tribes, along with a cohort of breast-feeding mothers in New York State.

The awards also established two new cohorts. One of these, the Illinois cohort of African American women, is a study intended to define the relationship between body burdens of mothers and health effects in infants. The other is the Michigan cohort of reproductive-age men and women, age 18 to 34. A final award is intended to enhance analytical methodology, specifically to discriminate among the dioxin-like coplanar PCBs and the non-coplanar PCBs within that broad class of compounds. Collectively, these awards will characterize exposure to the Great Lakes contaminants for all 11 of the critical contaminants identified by the International Joint Commission, including PAHs, alkyl lead, PCBs (including 67 congeners), and dioxin.

These grants also encompass the vulnerable populations that have been identified in collaboration and consultation with ATSDR's Board of Scientific Counselors. These populations include sport and Native American anglers, pregnant women, nursing mothers, fetuses and infant children, the urban poor, men and women of reproductive age, and the elderly.

Canada

The **Great Lakes Health Effects Program** (GLHEP) is a Health Canada initiative established in 1989 in response to health issues addressed in the 1987 Protocol to the Canada-United States Great Lakes Water Quality Agreement. Phase I (Health Canada 1994) of this multidisciplinary program covered a five-year period (1989-1994) and was allocated funding of $20 million. It combined research and action in partnership with the Canadian public and communities of the Great Lakes basin, and with agencies in Canada and the United States, to reduce the risk to human health from contaminants present in the Great Lakes.

GLHEP's mission to protect human health in the Great Lakes basin from the effects of exposure to environmental contaminants gave rise to three major goals:

- to determine the nature, magnitude and extent of effects on human health associated with exposure to contaminants (chemical, microbiological, radiological) from all sources of pollution in the Great Lakes basin
- to develop and implement strategies to reduce or eliminate risks to human health related to pollution in the

Great Lakes basin, and
- to increase communication and consultation among agencies and the public, and to provide timely, useful information to foster understanding and appropriate action on health and environmental issues.

GLHEP-supported research involving measurements of organochlorine chemicals in human adipose tissue, breast milk and blood has confirmed that humans in the Great Lakes basin are exposed to persistent toxic chemicals through the air we breathe, the water we drink, and the food we eat. The latter accounts for approximately 80-90% of human exposure to most persistent organochlorine contaminants. This proportion may be even higher for consumers of large quantities of Great Lakes fish or wildlife, in which these contaminants can readily bioaccumulate.

Epidemiologic studies have helped to identify several subpopulations at higher risk of adverse health effects because of their greater exposure to Great Lakes contaminants or their increased susceptibility. In addition to consumers of large amounts of contaminated Great Lakes sport fish or wildlife, people living in large or industrial urban areas, the elderly, the sick, young children, pregnant women, the developing fetus, and newborns/infants of mothers who consumed contaminated Great Lakes fish have been identified as subpopulations at higher risk for health effects. These health effects include exacerbated respiratory disease, immune system impairment, neurological developmental delays, psychosocial disorders, reproductive anomalies, and possibly others.

Studies conducted over the first five years of the Great Lakes Health Effects Program indicate that adverse reproductive, developmental and immunological effects, among others, may potentially result from exposure to Great Lakes contaminants, particularly in those belonging to the higher risk groups mentioned above.

The ways by which we measure health are also changing. Traditional health outcomes such as cancer and birth defects, which are well recorded (Health Canada 1995), are comparatively insensitive indicators of the effects of long-term low-level exposure to environmental contaminants. Increased interest in and attention to the more subtle potential health effects of chronic low-level exposures to mixtures of chemicals are evident in current and future research directions. These include the study of effects associated with hormone alteration, stimulation or mimicry, genital development, endometriosis, sperm abnormalities, sub-clinical immune dysfunction, respiratory effects, neurobehavioural and child development, and psycho-social health. People's perceptions of their health and the effects on social structures and functions are as direct as clinically demonstrated disease conditions. These findings form the basis for further study of these evolving issues, and serve as a valuable contribution to ongoing research on the human health impact of environmental contaminants in the Great Lakes basin.

3.1.2 Fish and Wildlife Toxicology

Reconsiderations of the Role of Contaminants on Salmonid Reproduction

The 1987 Protocol to the 1978 Great Lakes Water Quality Agreement introduced the concept of ecosystem objectives as part of the Supplement to Annex 1, which is concerned with the development of specific objectives. Progress on the development of these ecosystem objectives has been slow, but there are two species that have been accepted by the Parties as ecosystem objectives in relation to Lake Superior. These are the lake trout and a small crustacean called *Pontoporeia hoyi*. The acceptance of the concept of ecosystem objectives has had the potential of changing the focus of the Agreement from specific pollutants to the whole range of physical, chemical and biological factors in the Great Lakes basin ecosystem that could affect or could have affected species. There has been considerable progress in the past decade to investigate the role of a variety of factors that may control and may have controlled the status of lake trout, not only in Lake Superior but also in the other Great Lakes.

Lake trout stocks in the Great Lakes basin were extremely valuable species for the commercial fisheries until their demise between 1940 and 1960. The indigenous populations of lake trout from Lake Ontario and Lake Erie are extinct and the present populations in those and other lakes are maintained through plantings of hatchery-reared fish. The demise of the lake trout stocks in most parts of the Great Lakes has been attributed to the depredations of the sea lamprey, overfishing, eutrophication and destruction of the physical habitat. The Great Lakes Fishery Commission was formed in the mid-1950s to develop and implement control measures on the populations of sea lamprey. One of the stated goals of the Great Lakes Fishery Commission is the restoration of self-sustaining stocks of lake trout to the Great Lakes, but the attainment of this goal has been elusive. Recently, the Great Lakes Fishery Commission has been reconsidering the possible role of environmental contaminants in the demise of the lake trout, particularly through disruption of reproductive processes. The possible role of environmental contaminants in the demise of the lake trout stocks and in the failure to reestablish self-sustaining populations is therefore of immediate interest to those involved in advising the International Joint Commission on progress in research relevant to the Great Lakes Water Quality Agreement.

Lake trout is not the only species for which fisheries researchers are reconsidering the possible role of contaminants in reproductive failure. In the past 25 years a large sport fishery has grown for a variety of salmon introduced from the Pacific coast. Like most lake trout stocks, most Pacific salmon stocks have been maintained through plantings of young fish from hatcheries, since there is practically no recruitment to the stocks from fish raised in the lakes. In recent years, a series of severe failures in hatcheries rearing Pacific salmon from broodstock taken from the Great Lakes has occurred. Some of the shortfall in production has been supplemented by importation of eggs from the Pacific coast. But this importation has been severely restricted because of the possibility of transporting new diseases into the Great Lakes. For example, the introduction of bacterial kidney disease, which has devastated stocks of coho salmon in Lake Michigan, is suspected to have entered the Great Lakes through shipments of new eggs. Thus, fisheries researchers and hatchery managers are urgently seeking a solution to, and the cause of, this reproductive failure characterised by a severe incidence of mortality during the early life stages.

The Great Lakes Fish Health Committee of the Great Lakes Fishery Commission recently hosted two workshops on what has come to be known as Early Mortality Syndrome (Hnath 1994). One of the first problems that the participants confronted was the definition of the syndrome and the possibility that there might be more than one syndrome. The following is the consensus definition developed by the workshop participants:

> "Excess mortality (beyond expected losses) is occurring from the eyed egg stage through the period of first feeding, which cannot be explained by rearing environment, husbandry or infectious diseases. The primary indicators are above-normal loss of eyed eggs, loss of fry at hatch, and loss of fry from hatch to feeding. Clinical signs may include hyperexcitability, anemia, spiral swimming, dark coloration, lethargy (laying on the bottom or the surface), emaciation, feeding difficulties, and deformities."

There is not a high degree of specificity in this broad definition, and there is no lesion that is specific for the diagnosis of this syndrome. In addition, the affected fry may have signs similar to other diseases such as blue-sac, which is an edematous condition of the yolk sac, coagulated yolk, and white spot.

Two groups of researchers have found an effective treatment for early mortality syndrome in salmonids. The signs of early mortality syndrome are similar to the signs of various vitamin deficiencies. A series of experiments to expose samples of eggs to different vitamins, including thyroxine, astaxanthin, beta carotene treatments and thiamine, was undertaken to determine whether they could prevent the onset of the signs. The only vitamin that was efficacious was vitamin B1 or thiamine (Fisher et al. in prep.). There is also some evidence that exposure of the eggs to solutions of the hormone thyroxine similarly protects the eggs from developing the signs. These findings indicate that there is some part of the carbohydrate or lipid metabolism of the developing embryo or fry that is being affected (Hnath 1994). Applying these results to hatchery practice may enable fisheries managers to restock the Great Lakes with salmonids and thereby save this valuable sport fisheries from collapse.

Workshop participants focused much of their attention on the possible causes of the syndrome and of the thiamine deficiency. The group considered as many possible causes of the disease as might be plausible, including: brood stock management; genetics, nutritional deficiencies and changes in the foodwebs; microbiological pathogens; and environmental contaminants. Through the use of epidemiological criteria originally developed for investigating the causes of human disease, the group was able to discard several possible agents. For example, there was no evidence from the microbiologists that a microbial pathogen was involved in the disease. Similarly, various lines of evidence indicated that the syndrome was not specifically related to some aspect of brood-stock management or genetics, even though certain strains of organisms seemed to be more susceptible. This left the possibility that the syndrome was related to some aspect of nutrition, either through changes in the Great Lakes food webs or through deficiencies, and/or an involvement of environmental contaminants.

This hypothesis is remarkably similar to the independently-derived conclusions of researchers in Swedish hatcheries working on an analogous syndrome, called "M74," of fry of Atlantic salmon from rivers flowing into the Baltic Sea. Swedish researchers (Norrgren 1993) have posed the question of whether high mortalities in eggs and fry, and other kinds of reproductive failure of other fish species in the Baltic and in the North Sea, might be related to these factors. For example, Baltic cod exhibit a high mortality of eggs and fry, fry of perch that have been exposed to effluents of pulp and paper plants have a high mortality, and burbot from the Gulf of Bothnia have a high incidence of retarded gonadal development leading to sterility. An inverse relationship has been reported between hatching success of whiting from the North Sea and organochlorine chemicals.

There is a wide diversity of opinion about the possible role of environmental contaminants on reproduction of wild or feral fish stocks in the Great Lakes. Until recently, the consensus among fisheries managers was that environmental contaminants were not an important factor. Within the past five years, a series of toxicological experiments have laid the basis for a retrospective risk assessment that is challenging this consensus. Eggs of lake trout are among the most sensitive organisms to exposures to 2,3,7,8-tetrachlorodibenzo-p-dioxin. There is a sharp increase in the embryo mortality above 50 parts per trillion in the eggs, and complete mortality in eggs with 100 part per trillion (Walker et al. 1991). The questions now posed to the scientific community are: whether the release of dioxin into Lake Ontario contributed to the collapse of the overfished stocks of lake trout; whether other stocks and other species in other locations were also affected; and what is causing the thiamine deficiency.

Micro-contaminants in Lampricides

The central policy of the Great Lakes Water Quality Agreement is that the discharge of any or all persistent toxic substances shall be virtually eliminated. One of the properties of some persistent toxic substances is that they induce the level of activity of liver enzymes responsible for detoxifying chemicals. This induction of **mixed function oxygenase** (MFO) activity in liver samples from fish and other organisms has been used extensively to indicate the presence of persistent toxic substances, such as **polychlorinated biphenyls** (PCBs), dibenzo-p-dioxins and furans, in the Great Lakes environment.

An intensive series of studies was undertaken by fisheries researchers during the 1980s and early 1990s to determine the identity of substances that caused MFO activity in fish, associated with the effluent from pulp and paper operations. Much of this work has been undertaken at pulp and paper mills located on the shores or tributaries of Lake Superior (Munkittrick et al. 1992, 1994 and Servos et al. 1994). Fisheries researchers found that fish from Whitefish Bay and Batchawana Bay, pristine areas that are remote from pulp and paper operations, had elevated levels of MFO activity. After further study, research may determine that lampricides may have been responsible for elevated MFO activity.

Lampricides have been used for more than 30 years to reduce larval lampreys in nursery streams. **Three-trifluoromethyl-4-nitrophenol** (TFM) has been applied to most nursery streams on a three-year cycle, at a rate of 50 tonnes per year. The other substance is 2',5-dichloro-4-nitrosalicylanilide, which has a trade name of Bayer 73, and may be applied alone or in combination with TFM.

By placing white suckers in cages in streams being treated with lampricides, fisheries scientists showed that there was a five-fold induction of MFO activity two days after exposure (Munkittrick et al. 1994). These findings were confirmed in laboratory experiments using the same batch of lampricide. The technical formulations of TFM showed this biological activity, in contrast to the Bayer 73 formulations, which showed none of this activity. By using **high performance liquid chromatography** (HPLC), chemists isolated the TFM from the TFM formulations and demonstrated that it did not induce MFO activity. It was concluded that the activity was caused by other chemical compounds in the technical formulations (Servos et al. 1994).

Analysis of the TFM formulation showed that there was no detectable level of polychlorinated dibenzo-p-dioxins, furans and polynuclear aromatic hydrocarbons. These findings indicated that the contaminants in the lampricide were not one of the substances that have previously been known to cause MFO induction in the Great Lakes environment.

Significant progress has been made in isolating and identifying the chemical(s) in the TFM formulations responsible for the MFO activity. Through fractionation using solid phase cartridges, the TFM was removed from the formulation and the MFO activity shown to be associated with two distinct fractions, indicating the presence of at least two substances that have MFO activity. The major substances in the fractions were diphenyl ethers, but when these compounds were synthesized they were shown not to induce MFO activity in fish. It was concluded that the compounds associated with the MFO induction must be minor components of the TFM formulation, and that these compounds would be at very low concentrations in the receiving waters of Lake Superior after application to the tributaries.

Further fractionation with HPLC and analysis with high resolution gas chromatography/mass spectrometry has lead to preliminary identifications of several chemicals, including additional chlorinated diphenylethers and chlorotrifluoromethylnitro-p-dioxin. Substituting the dibenzo-p-dioxin structure with a trifluoromethyl or nitro groups only slightly changes and may even enhance the toxicity relative to a similarly substituted polychlorinated dibenzo-p-dioxin. These substances must be tested to determine their persistence and toxicity, and particularly their potential to cause metabolic disturbance such as the reduction of circulating sex steroids in fish.

Immunotoxicology

Introduction

In the past five years, the Great Lakes scientific community has become interested in the subtle effects of chemicals on the structure and functioning of exposed organisms. Toxicologists have long been interested in the quantities or concentrations of chemicals that directly caused increased mortality. More recently, they have turned their attention to the more subtle changes that can be detected at lower concentrations, particularly in offspring (Colborn et al. 1993). A new appreciation has developed of the ways in which these subtle effects can have devastating implications for populations of valuable fish and wildlife resources. The development and functioning of the immune system is one of these subtle endpoints, and toxicologists have made some remarkable advances in this science in relation to effects on fish and wildlife in the Great Lakes.

A functional immune system is essential to defend against pathogenic agents and cancer. Exposure to chemicals that are immunotoxic may result in increased susceptibility to disease because the immune system's competency is compromised and its resistance to disease is diminished. Aquatic environments, such as the Great Lakes, facilitate the survival and dispersal of pathogens that infect aquatic organisms. Thus, the competency of the immune system of aquatic organisms such as fish is particularly important, because they are continually presented with challenges from pathogens. Subtle changes in the immune system, caused by exposures to chemicals, may lead to outbreaks of disease in aquatic organism populations (Anderson and Zeeman, 1995).

The immune system is particularly vulnerable to chemically-induced damage because the cellular components continually grow and differentiate during development and throughout the life cycle of the organism. In addition, the immune system has a "memory," and repeated or chronic, low-level exposures to immunotoxic chemicals may have more of an effect on the survival and functioning of organisms than a single, acute exposure to a higher concentration (Weeks et al. 1992).

Immunotoxic Chemicals

Many environmental chemicals have been shown, particularly in mammals, to affect or modulate the development and functioning of the immune system. The major classes of compounds that have been identified as immunomodulators include pesticides, polynuclear aromatic hydrocarbons, organochlorine compounds such as polychlorinated biphenyls, and organometallic compounds such as tributyl tin (Dunier and Siwicki, 1993). While the science of immunotoxicology in fish is still in its infancy, chronic, low-level exposure of fish to pesticides and polynuclear aromatic hydrocarbons has been suspected for some time of predisposing fish to disease through immunosuppression.

For example, several experimental studies have established the immunomodulatory effects of polychlorinated biphenyls in fish. In one study, Aroclor 1232 was injected intraperitoneally into channel catfish (*Ictalurus punctatus*) that had been immunized with an attenuated strain (bacterin) of *Aeromonas hydrophila* (Jones et al.

1979). The PCB-treated fish showed reduced functioning of the macrophages, and when challenged again with *Aeromonas hydrophila*, all exposed fish died, while the controls survived. These results indicate a lack of response to the bacterin and a decrease of phagocytic function in exposed fish. The experiment demonstrated that this PCB suppressed the normal functioning of the immune system in the treated fish.

Similarly, there are several examples of experiments in which organophosphate and carbamate compounds have caused immunomodulatory effects in fish. Exposure of lake trout and coho salmon to malathion decreased spleen weight and size, and the numbers of lymphocytes in the spleen (Zeeman and Brindley, 1981). Carp exposed to trichlorfon exhibited suppression of immune function (Siwicki et al. 1990). However, dichlorvos, a known immunosuppressor in certain mammals, did not (Cossarini-Dunier et al. 1991). Salmonids exposed to carbaryl at 10.2 ppm for 100 days showed atrophy of lymphoid organs and depletion of lymphocytes. Spot exposed to the much lower concentration of 0.1ppm showed a significant increase in susceptibility to parasitism by sporozoans (Walsh and Ribelin, 1975).

Indicators

Measuring the immune system components or cellular function provides a very sensitive endpoint of exposure to environmental contaminants (Weeks et al. 1992). For example, immunotoxic chemicals may cause suppression or enhancement of the immune system, affect the ability to produce antibodies through the humoral system, or the ability of macrophages to clear pathogenic microbes. Macrophages provide the first line of defense against infectious agents, and are thus an especially important component of the fishes' immune system. Similarly, the activation of leukocytes is a critical component of immune system functioning. Measurements of macrophage functioning and of the activity of white blood cells have been used as sensitive indicators of effects of chemicals in aquatic environments.

For example, fish from the Elizabeth River in Virginia, which is highly polluted with polynuclear aromatic hydrocarbons, have a high incidence of disease and neoplasms, which often indicates immune system dysfunction. Tests of macrophage function were used to compare the immune competence of fish captured from the Elizabeth River with fish captured from the relatively unpolluted York River (Weeks et al. 1986). Macrophage function was significantly depressed in three different species living in the Elizabeth River compared to fish from the York River. Similarly, mummichog (*Fundulus heteroclitus L.*) from the Elizabeth River showed suppression of the activity of a subset of white blood cells (natural cytotoxic cells) that are important in tumor surveillance, compared to the fish from the York River (Faisal et al. 1991). Thus, assays of macrophage function and natural cytotoxic cell activity in captured fish proved to be sensitive indicators of the effects of toxic chemicals in this aquatic environment.

Another study investigated the likely effect on mammalian predators of contaminated fish. Coho salmon (*Oncorrhynchus kisutch*), which had accumulated a variety of halogenated aromatic hydrocarbons, were fed to mice. The mice were immunized with red blood cells from sheep to assess whether this exposure to contaminants led to immuno-suppression. While no effect was seen on lymphocyte numbers, antibody response was depressed proportionally to the elevated contaminant levels (Cleland et al. 1989).

Other Endpoints

In the past, many non-specific indicators of immune compromise have been linked with exposure to environmental chemicals in fish (Dunier 1994). These endpoints have included decreases in the size of the spleen, in the leucocyte counts and in the phagocytic ability of the macrophages. Similarly, decreases in the levels of plasma proteins have been recorded, which can reflect a lower level of circulating antibodies.

Several examples of these changes are available from experiments with organochlorine chemicals. Goldfish exposed to DDT have shown a decrease in immunocompetence as demonstrated by a decrease in plasma proteins, decreased spleen weight and suppression of the antibody response when exposed to a foreign antigen, bovine serum albumen (Zeeman and Brindley, 1981). Salmon exposed to 0.35 ppb of endosulfan for 25 days had atrophy of lymphoid organs and a decrease in the number of white blood cells (Zeeman and Brindley, 1981). Channel catfish exposed to mirex (21 or 42 mg/kg/day) had decreased counts of leucocytes and thrombocytes (Zeeman and Brindley, 1981). Exposure of trout to endrin has caused a decrease in lymphocyte response (Bennett and Wolke, 1987). Catfish exposed to lindane (1.3mg/l) showed a significant reduction in leucocyte count and antibody response to *Aeromonas hydrophila* (Saxena et al. 1992).

In the Great Lakes basin, no direct evidence yet exists as to whether or not PCBs are affecting the immune system of introduced Pacific salmon. An in vitro system has been developed, focused on the early events in the activation of lymphocytes from the spleen of chinook salmon when stimulated with compounds that induce mitosis (Noguchi et al. 1995). Flow cytometry has been used to identify lymphocytes of bursa and thymic origin and thereby to investigate the susceptibility of these cells to the specific PCB congeners. This technique will help in determining whether PCBs in the waters of the Great Lakes are contributing to the susceptibility of Pacific salmon to disease through effects on their immune status.

Research has been undertaken on the immune status of fish-eating birds in the wild and exposures to environmental contaminants (Grasman 1995). In herring gull adults and chicks from various locations across a wide range of concentrations of organochlorine compounds, the heterophil to lymphocyte ratio decreased as a physiological index of contaminant exposure increased. In the chicks the mass of the thymus decreased as the index of the contaminant exposure increased. These results indicated that the immune systems in this species had been affected by the contaminants, though neither response was specifically correlated with the concentration of PCBs in the liver. The competence of the immune system was measured in herring gull and Caspian tern chicks by injecting phytohemagglutinin, a mitogen derived from plants, into the skin of the wing and measuring the response after 24 hours. This is a measure of the immunity mediated through the cells from the thymic system. In both species the measured response on the skin showed that immunity decreased as the egg PCB concentrations increased. Both the field observations of thymic atrophy and the suppression of the immune response mediated by the thymic system are consistent with the effects of PCB and dioxin in laboratory animals.

3.1.3 Status of the Research Inventory

Since the Great Lakes Water Quality Agreement was first signed in 1972, a continuing terms of reference has included examining and advising the Commission on the adequacy of research, and promoting research coordination. Over the intervening years a series of research inventories have been produced to meet these requirements. This responsibility has been a relatively resource-intensive undertaking and during the 1993-1995 biennial cycle the Council completed it through two of its member organizations, the National Oceanic and Atmospheric Administration and the Ontario Ministry of Environment and Energy. Staff at the Great Lakes Regional Office coordinate the requests for information from the principal investigators and forward the information to these two agencies.

A series of changes has also occurred in the preparation of the research inventory. For example, information is now collected on research projects undertaken on a much wider variety of topics to reflect the ecosystem approach to management of the Great Lakes Basin Ecosystem. In addition to the research on pollution by nutrients, toxic substances and radionuclides, topics include the introduction of exotic species, land use and wetlands, shoreline and upland habitat, resource management including fisheries, wildlife and forestry, and natural ecological processes. These categories make up a new classification system.

In the past, it has been a challenge to produce and publish the research inventory in a timely manner. The cost has been substantial and the data have frequently been out of date by the time that the document was completed. In addition to undertaking the work through compatible binational systems within the two member agencies, the Council decided to make the inventory accessible through the **Great Lakes Information Network** (GLIN) and through computer disk, but not through written publication.

3.1.4 Recruitment, Training and Development of Scientists

The 3R s: Recruitment, Replacement and Retention of Scientists in the Great Lakes

In fall 1989, the Council of Great Lakes Research Managers convened a Vision Workshop at the Niagara Institute and identified the issue of the recruitment, replacement and retention of scientists as an important factor in the ability of the Great Lakes research community to undertake future research. While the International Joint Commission was setting priorities for the 1993-1995 biennial cycle, it requested the Council of Great Lakes Research Managers to examine the adequacy of current training programs to fill future needs for scientists for Great Lakes research.

The strengthening of the research community in the Great Lakes basin begins with the creation of a healthy research climate that attracts and holds expertise. That climate is established and maintained, in part, by the opportunities offered. It is not something that can be addressed only by the infusion of money, although that is a vital ingredient for the stability essential for good science. Nor can it be reasonably expected from the provision of physical facilities alone, although that can be useful to concentrate effort efficiently. And it is not something that can be initiated solely from a vision or mission statement, although that is often the basis for a commitment that sustains the scientist's effort, both personally and professionally. The processes necessary to strengthen research includes all these things but goes much further and leads to the establishment of a vigorous intellectual environment that by its own power attracts and develops skill, encourages initiative and provides incentive for innovation. In the field of ecosystem sciences, it is increasingly requiring transdisciplinary expertise and synthesis. This is what must be maintained and nurtured in the Great Lakes.

The current members of the scientific research community in the Great Lakes and St. Lawrence River comprise an aging population. The Council of Great Lakes Research Managers has raised the need to replenish this population with well-trained graduates prepared to investigate issues in a multidisciplinary manner. Although it is a significant challenge, a vigorous intellectual environment must be maintained in the Great Lakes region if the advances in scientific knowledge are to be applied to restoring and maintaining the integrity of the waters of the Great Lakes Basin Ecosystem. How can scientists be recruited from across the continent to work in the Great Lakes basin? How can graduate students be attracted? How can universities and government laboratories be properly persuaded that the basin requires their attention? And how can retraining be introduced to assist those who have decades of experience in addressing the changing needs of research?

U.S. Perspective

The Great Lakes Basin Ecosystem encompasses a large geographic area, and thus its research requires a large-scale approach with integrated and multidisciplinary programs. These large scale phenomena are expensive to investigate and control. In the 1960s, the United States federal government provided the funds, particularly to universities, to undertake the necessary research. In the present economic climate, it is not likely the federal government will have the funds to provide the economic incentives that previously sufficed.

Universities have a major responsibility for research on large lakes due to their expertise, unique equipment and facilities, including libraries, powerful computing capabilities, and major museums. They also develop future scientists whose research orientation is often determined while in school.

Supply

A review of the trends in recruitment and production of graduate students in disciplines germane to the Great Lakes is encouraging. Overall in the United States, enrollment in the earth, atmospheric and ocean sciences peaked in 1984 at about 15,655 students and has slowly declined to a low in 1989 of about 13,849 students. Students in the biological sciences remained fairly constant from 1975 through 1987, with a sharp increase from 47,138 in 1987 to 52,120 in 1991 (Table 1). Overall the trend was for a gradual increase from 61,547 in 1984 to 66,867 in 1991 (NSF 1992).

Graduate student enrollment in Ph.D. granting institutions from states bordering the Great Lakes provide a clearer picture of the enrollment trends of students that are probably going to be the major contributors to the pool of potential recruits. The science and engineering student enrollment overall has remained fairly steady from around 130,000 in 1983 until 1990, however there was a marked increase in enrollment to over 142,000 in 1991. Enrollment data from the four major institutions producing the bulk of the graduates in science and engineering in the basin provide a more precise figure, from the Universities of Wisconsin, Michigan, Minnesota and Ohio State. Overall enrollment in these four institutions, which are four of the five in the country with the highest enrollment in science and engineering, has continually increased at a slow rate from 1984 to 1991 (Table 1).

Based on these data alone, it would be very difficult to argue that there are not enough students graduating from universities in the basin to replace current Great Lakes scientists. There are, however, some problems. Even though the data do not indicate a serious overall problem, it is too general to determine whether there will be enough limnologists, ecologists or aquatic chemists in the future. What are the enrollments in the key disciplines needed in the basin? Barring evidence to the contrary, it is generally assumed that there is a direct correlation between the number of students in science and engineering and the numbers in any particular discipline.

These data do not address the nature of the training or the quality of student being produced. It is reasonable to assume, however, that if there is a large pool of scientists from which to draw, those of a high calibre can be attracted to Great Lakes research if conditions are conducive. A more serious concern is that the National Sea Grant College Program in the United States has seen gradual declines in appropriations (inflation adjusted), number of graduates involved in the program, and the number of principle investigators undertaking research projects in the Great Lakes basin (Figure 1). Since Sea Grant is one of the primary supporters of Great Lakes academic research, changes in their funding and enrollment are particularly relevant.

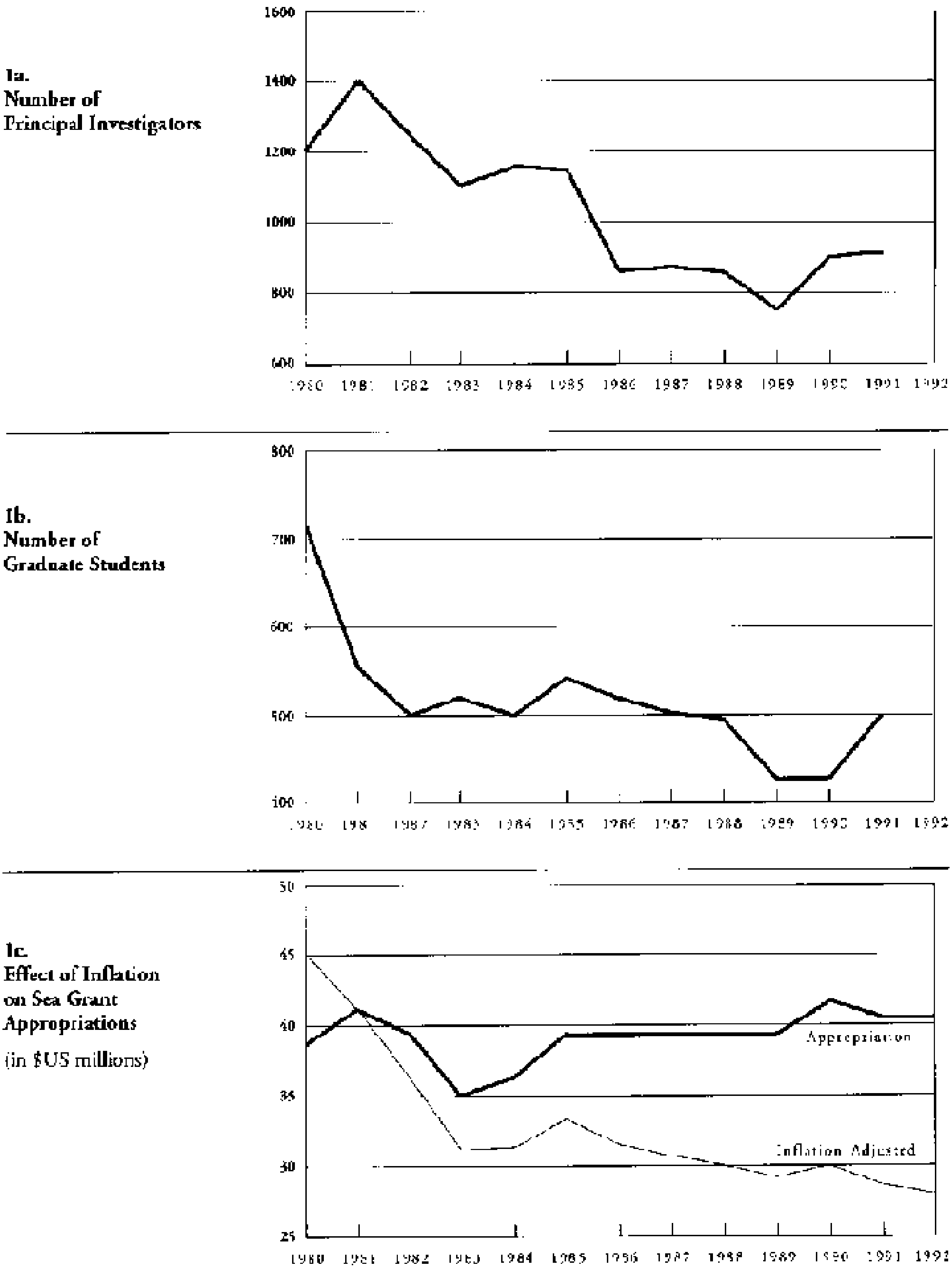
1a.
Number of
Principal Investigators
1600
1400
1200
1000
800
600
1b.
Number of
Graduate Students
800
700
600
500
1c.
Effect of Inflation
on Sea Grant
Appropriations
(in $US millions)
50
45
40
35
30
25
Appropriation
Inflation Adjusted
1980
1984
1985
1989
1992

Figure 1.

National Sea Grant College Program: Trends in number of principal investigators (1a), graduate students (1b), and effect of inflation on appropriations (1c).

Demand

The demand for research scientists within the Great Lakes basin is linked to funding of research. Government laboratories and agencies, state departments of natural resources and health departments are some of the primary government units supporting research. Additional research is accomplished within the universities by faculty investigators. The latter play an important role because they conduct research and train graduate students in activities relevant to the Great Lakes. Funding at this level has never been adequate or stable. University researchers have had to obtain funds in an opportunistic fashion, which precludes long-term studies and restricts work to studies of limited scope.

In addition, it is at the university where training for interdisciplinary research begins. Funding for this type of work has not been abundant. Improvement of basinwide research funding has the greatest potential for improvement of research.

Conclusions for U.S. Institutions

Overall enrollment in science and engineering in the nation as a whole, in universities in the states bordering the Great Lakes, and in the four major state universities in the basin all show a slow but definite increase in enrollment of graduate students in the sciences. No specific evidence indicates that there will be a shortage of students graduating in the disciplines needed to address Great Lakes problems. Declines in the funding of the Sea Grant Program, after adjustment for inflation, may limit the enrollment of graduate students in relevant areas.

Consequently, it appears that the supply side of the equation is adequate in the U.S. It makes sense, however, to encourage the development of as large a pool of scientists as possible from which to draw to insure the highest quality science that can be generated to address issues that have not yet been identified but that will inevitably require research in the future. More important to Great Lakes research is the lack of appropriate, stable, long-term funding and the need to create an intellectual climate that will attract good scientists to the region. The supply of young investigators is there. The senior scientists who can serve as mentors are still in place. The need lies in research funding which can bring them together.

Canadian Perspective

Managers of Canadian government research laboratories have expressed concern about the possibility of shortages of highly qualified scientists and engineers in the future. There is an uneven age distribution in the scientific community, with a large cohort of middle-aged scientists. Over the last 10 years, the rate of departure for scientists and engineers in the federal government varied between 4% and 5%. The retirement of the scientists from this cohort over a short period, in the near future, therefore might deprive the research and regulatory communities of a wealth of experience.

Supply

Enrollment in departments of biology and agriculture in Canadian universities increased by 16% in the 1980s (NSERC 1989). Similarly, enrollment in Canadian Ph.D. programs in the natural sciences increased significantly (AUCC 1991). Thus there is no indication of a likely shortage of qualified professionals to replace those who are about to retire.

Demand

Total federal government personnel on a national basis, engaged in activities in the natural sciences and engineering, increased from 24,405 in 1981 to a peak of 25,905 in 1984. There was, however, a 5% decrease by 1990-1991 to 24,628. The scientific and professional category, however, experienced a steady growth from 7,635 in 1981-82 to 8,719 in 1990-91.

Situation at Great Lakes Research Laboratories

Table 2 represents the findings of a poll on the perceived staffing requirements for university graduates at seven major federal and provincial government facilities undertaking Great Lakes research. Staff turnover is presently between 5 and 10% because of budget constraints. This rate might increase as the large cohort of middle-aged scientists reach retirement age within the next 5-10 years. In some years and in some organizations, up to one-half of the professional scientific staff may leave.

All laboratories, except fisheries, reported a sufficient quantity of graduates. Only the environment and wildlife laboratories, however, were satisfied with the quality of the candidates and did not feel the need for retraining.

Conclusions

- Many government research scientists will be retiring by the end of the 1990s.
- Overall production of science and engineering graduates in the basin has risen slightly over the past decade.
- There does not seem to be a shortage of qualified graduates to replace the present professionals when they retire.
- The timing to recruit qualified graduates to replace the professionals who are retiring in the next ten years may be crucial for the continuity of Great Lakes research.

3.2 Impacts of Changes on Lake Erie Ecosystem

3.2.1 Application of the Ecosystem Framework to Zebra Mussels in Lake Erie

During the past five years, the Council of Great Lakes Research Managers has developed an ecosystem framework to aid managers in selecting priorities for research, and to assist policymakers to explore options. The Council, in collaboration with the United States Environmental Protection Agency and the Canada Department of Fisheries and Oceans, contracted with Dr. Steven Underwood and Dr. Richard Duke of the College of Architecture and Urban Planning at the University of Michigan in Ann Arbor, to undertake this developmental work. The objective was to develop a schematic diagram (see Figure 2) to link knowledge about the natural systems in the Great Lakes basin with societal and institutional processes and thereby aid in the selection of research priorities and policy options.

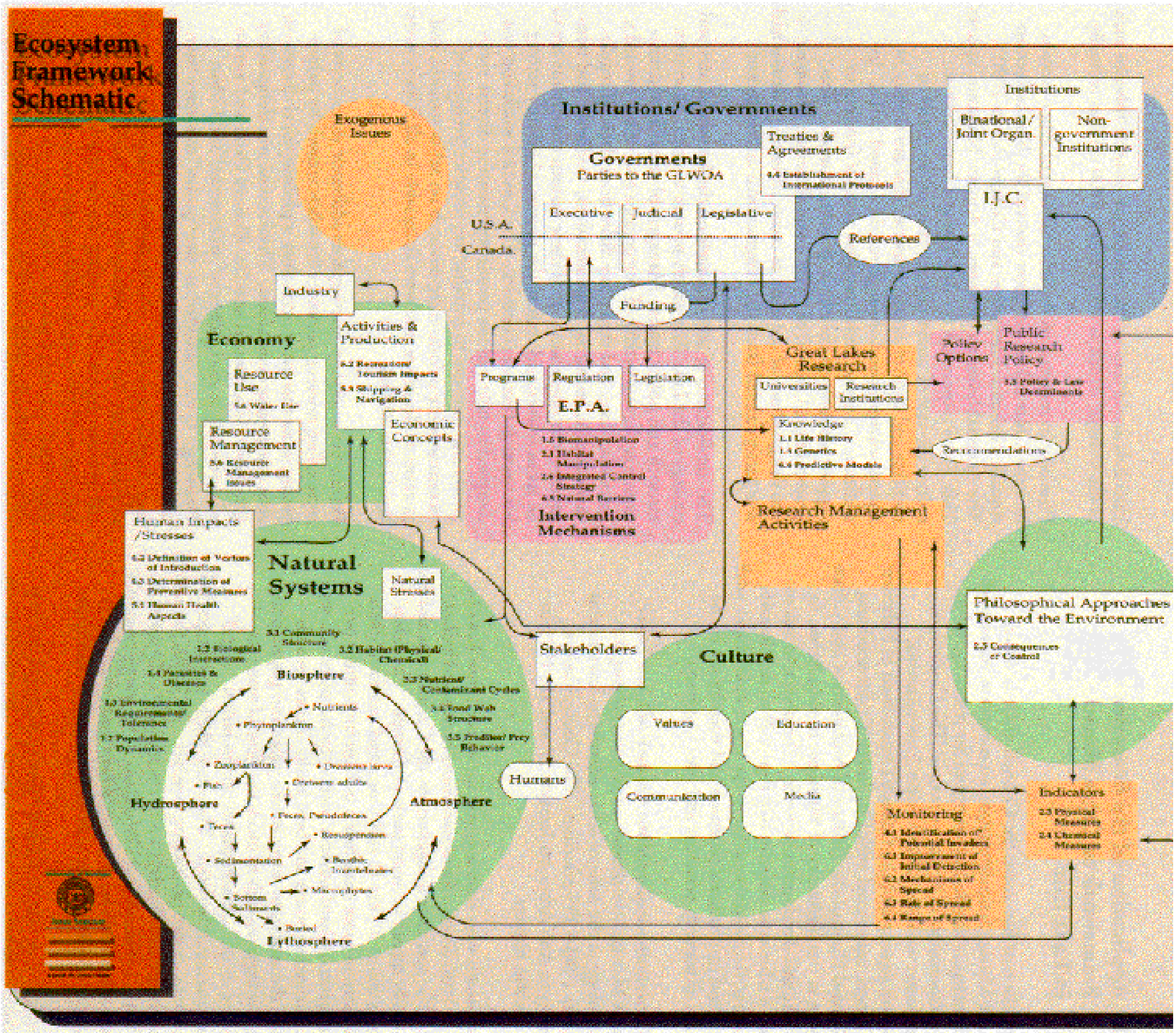

Figure 2
Ecosystem Schematic

The Commission requested the Council of Great Lakes Research Managers to provide advice on applying the methodology to the issue of zebra mussels in Lake Erie as part of its 1993-1995 priorities. The Council held a workshop in Ann Arbor on January 17 and 18, 1995 to carry out this request.

Zebra mussels were inadvertently introduced into Lake St. Clair in 1986 when a European vessel exchanged ballast water. The species is indigenous to the Caspian Sea and had successfully spread to many parts of Europe. The zebra mussel is about 2.5 cm (1 inch) long and can form dense populations of more than half a million individuals per square meter on hard surfaces such as rocks, piers and sea walls, navigation buoys and boat hulls. Zebra mussels colonize the insides of water intake pipes and populations may grow large enough to block the flow of water to municipal drinking water plants and to industrial and power-generation facilities. The sharp shells have degraded the aesthetic quality of bathing beaches. By 1990, the zebra mussels had redistributed to other waterways as far away as New York, Louisiana and Oklahoma. The quagga mussel is a closely related species discovered later and which forms substantial populations on soft surfaces such as sediments.

The burgeoning populations of zebra and quagga mussels filter large quantities of water and remove the plankton. In

Lake Erie, "catastrophic" declines have occurred in plankton populations and this has raised concerns that the major fisheries will be affected, since plankton is at the base of the food chain and therefore essential for the growth of juvenile fish. The effects of the mussels on Lake Erie food webs in Lake Erie could lead to the collapse of valuable fisheries such as the walleye, which is worth about $900 million annually.

Primarily in response to the introduction of zebra mussels into the Great Lakes, Congress enacted the Nonindigenous Aquatic Nuisance Prevention and Control Act in 1990. The Act establishes an interagency Aquatic Nuisance Species Task Force responsible for developing a framework to reduce the risk of unintentional introductions and to monitor and control nuisance species that are already in aquatic environments throughout the United States. In addition, Congress authorized five years of funding to support research on the effects of zebra mussels. This project of the Council of Great Lakes Research Managers was designed out of the need to create research priorities and was partly funded from the congressional authorization.

The implications of zebra mussels on the beneficial uses and ecology of the Lake Erie waters present a series of complex research and policy issues. Managers of research organizations may have a variety of perceptions and values toward a particular issue, and these may differ from those of regulatory officials, industrial representatives, academics and non-government organizations. If these various viewpoints are to be taken into consideration, the process of priority setting for research becomes complex. The Council workshop was designed to help various people representing diverse viewpoints and interests to examine the complex problem of recommending priorities for research on zebra mussels, and to come to decisions that were acceptable to all (Underwood and Duke, 1995a).

Before the workshop, participants addressed the process of reconciling research priorities for zebra mussels by participating in an exercise to introduce a philosophical discussion about managing ecosystems. This exercise was designed by Dr. Steven Underwood and Dr. Richard Duke and a team of coworkers at the College of Architecture and Urban Planning. It was modelled on the "games" that have been developed over the past four or five decades for understanding complex processes. The former Secretary of the Council of Great Lakes Research Managers, Peter Seidl, was influential in initiating and encouraging the development of this heuristic tool for understanding ecosystem management. Peter Seidl was on a leave of absence from the International Joint Commission with the World Bank when the plane in which he was travelling disappeared in the Bolivian jungle. As a tribute to the enthusiasm that Peter showed to his colleagues on this project, this exercise has been called the SEIDL Game. The acronym is comprised of the words Sustainable Environmental Integrative Development of the Lakes. Copies of the reports (Underwood and Duke, 1995b) associated with the workshop, including the SEIDL Game, are available on computer disk.

The following is a summary of the workshop results. Twenty-one workshop participants were assigned to seven teams that each represented one of the following perspectives: ecophilosopher; physical scientist; policymaker; program manager; research manager; social scientist; and stakeholder. The participants considered and ranked the following six research foci, which were part of the proposed Aquatic Nuisance Species Program developed by the Aquatic Nuisance Species Task Force:

Biology/Life History of Nonindigenous Species

> *A basic understanding of the life history and population dynamics of recently introduced species is required in order to predict the response of the ecosystem to invasion, and to determine biological characteristics that may guide research to the discovery of effective, ecologically safe, and economically feasible control measures. Reviews of existing research literature in conjunction with primary biological research to consider the areas of life history, population dynamics, physiology and behaviour, genetics, parasites and diseases may be especially pertinent in determining an organism s vulnerability to particular control alternatives. Information on the ecological and environmental tolerances of species is necessary to determine the potential geographic limits of infestation and to predict which indigenous species and their habitats are most likely to be affected by the invasion.*

Control and Mitigation of Nonindigenous Species

> *While temporary measures may mitigate the effects of invading organisms, the only truly effective*

means of control will be identified through long-term research. An example of this approach is the successful control of sea lamprey populations in the Great Lakes. Future success in controlling the damage from newly invading nonindigenous species must be predicated on the same research strategy which investigates the entire suite of physical, chemical and biological requirements of each nonindigenous species. Innovative and effective control techniques specifically targeted to nonindigenous invaders can only be determined through knowledge of the organisms behaviour, physiology, genetic and immunochemical characteristics. Thus, a well-balanced research program on control and mitigation requires as a point of departure, information about these factors.

From this base of information acquired under the biology/life history research area, the research program in control and mitigation can move into the investigation of a variety of control measures: engineering (redesign of water-intake pipe, etc.); physical (scraping, filtering, etc.); biological (parasites, predators, etc.); and physico-chemical (heat, pH, etc.). These lines of investigation should be paralleled and include both short-term and long-term means of control and mitigation of nonindigenous species. Finally, control of nonindigenous species must be ecologically acceptable and responsible. In particular, research on proposed biocides would include consideration of their toxicity to other organisms, persistence in the environment, and bioaccumulation.

Ecosystem Effects of Nonindigenous Species

Any new organism introduced to an existing ecosystem has the potential to alter or disrupt existing ecosystem relationships and environmental processes. The implications of a nonindigenous species invasion of an ecosystem, especially in relation to competition for food with other species ranging from zooplankton and benthos to juvenile fish, may be far-reaching. The invasion of nonindigenous species can significantly affect the populations of other organisms that are important components of the existing food web, ultimately leading to either overpopulation or demise of important existing species. In addition, some nonindigenous organisms can influence, and possibly significantly change, environmental processes that determine water quality, such as the distribution and cycling of particulates and toxic contaminants, and the productivity of the affected water bodies.

Therefore, a high priority of any nonindigenous species research program must be to identify and evaluate the likely ecosystem and environmental effects and changes that the new organisms, at each stage of its life history, is likely to produce. Such information will assist natural resource managers in making decisions that will minimize, and/or accommodate as much as practical, the ecological and environmental impacts that invading organisms have on established biota and their habitats.

Prevention of Introduction of Nonindigenous Species

Once introduced and established in an open aquatic system, nonindigenous species have proven impossible to eliminate. While effective means may be found to control these organisms at some ecological or socio-economic level of acceptance, in most cases little can be done to minimize ecosystem impacts and resulting resource losses. Emphasis, therefore, should be placed on preventing the introduction of new nonindigenous species into the system.

First, the potential means of introduction must be identified. Then, research should focus on establishing cost-effective, realistic methods of prevention. For example, ballast water discharge is an important vector for nonindigenous species introduction in the Great Lakes. Strategies must be developed to effectively eliminate this source of introduction without imposing undue hardships on the shipping industry. Strategies to eliminate other means of nonindigenous species introductions, such as intentional release, opening of canals, accidental release, and so on must be examined in a similar fashion.

In addition, not all introduced species become widespread and abundant. An examination of life history characteristics and past dispersal patterns in other aquatic environments worldwide can identify those species most likely to spread into and colonize the Great Lakes.

Reducing the Spread/Distribution of Nonindigenous Species

> *The scientific ability to predict the spread of an established nonindigenous species (that is, a viable reproducing population) is dependent on knowledge of the species environmental requirements and its dispersal mechanisms, which allow it to reach new areas where environmental conditions are favourable for growth and reproduction. Most nonindigenous species have been introduced and spread by anthropogenic activities (ship ballast, boats, the pet industry, and so on). However, the mechanisms by which dispersal occurs are often unique to each species and are usually discovered once geographic range extensions have already occurred.*
>
> *Basic understanding of nonindigenous species biology and documentation of past modes of dispersal can be used to establish likely future dispersal mechanisms. Once dispersal mechanisms are identified for individual established nonindigenous species, proper safeguards and international protocols can be developed to prevent and/or slow the spread to uninfested areas. Such safeguards and protocols may also be applicable to preventing the spread of new, not-yet-established nonindigenous species. Analysis and identification of past and possible future dispersal mechanisms of nonindigenous species will enhance the ability to control and mitigate the impact these species may have on the ecosystem.*

Socio-economic Research Costs and Benefits of Nonindigenous Species

> *Natural resource managers need to be aware of the potential effects of nonindigenous species on the economy and society so that they can adjust their management strategies to control and direct the impacts. Experience with most nonindigenous species indicates that negative impacts usually predominate over positive ones; nonetheless, research should address both aspects for the benefit of society. Research should focus on the potential impacts on human health in terms of spread of disease, concentrations of pollutants, and contamination or purification of drinking water sources. Economic impact investigations should broadly examine effects on all productive uses of aquatic resources including the sport, commercial and tribal fishing industry; the recreation and tourism industry; shipping and navigation needs; and municipal and industrial water users. Economic uses of nonindigenous species, for example as food for domestic animals or fertilizer for gardens and crops, should be evaluated. Finally, research results should be used to provide a scientific basis for developing sound policy and environmental law and for education and technology transfer on socio-economic effects.*

The rank order of these six foci by the participants, from their particular perspective, was:

1. prevention of introduction
2. socio-economic considerations and analysis
3. control and mitigation
4. ecosystem effects
5. spread of established zebra mussels, and
6. biology and life history.

Each of these six research foci comprises a series of sub-elements and the workshop participants selected and ranked these and prepared the following statements of the recommended research priorities for zebra mussels in Lake Erie and for the introduction of other exotic species, from their perspective.

According to the *Ecophilosophers*, the new focus can be organized into a network with three equally important or complimentary nodes. These nodes include:

1. Direct, visible and immediate reactions for curvature and/or correction at multiple locations
2. Learning to adapt constructurally, or in adaptive environmental management (in both the medium and long term)
3. Prevention at a continental, global and long-term level.

The *Research Managers* adopted a different interpretation of the new research focus and its defined elements. They presented five basic needs to be addressed by zebra mussel research:

1. To develop protocols/policies to minimize/prevent introduction of additional exotic species
2. To assess the financial impacts of ballast controls on ocean-going ships
3. To develop protocols/policies to contain/control new established species
4. To develop long-term, integrative control strategies to keep Lake Erie zebra mussel populations under acceptable levels (to minimize the ecosystem impact)
5. To develop cost effective and environmentally benign controls using physical processes for water users.

Policymakers highlighted stakeholders and potential interest groups in their statement of research priorities. They emphasized that research priorities for zebra mussels in Lake Erie should be inclusive of preventive and mitigative approaches. Preventive approaches include the identification of potential invaders, their environmental requirements and tolerances, and the determination of preventive measures through the development of legislation and appropriate technology, particularly related to shipping and navigation. After an invasion by an exotic species, mitigative approaches become publicly mandated. Predictive models should then be developed to establish effects on nutrient and contaminant cycling, integrated control strategies through understanding of the consequences of the various control options, and the development of physical rather than chemical control measures.

The *Social Scientists* adopted a broader view in their statement of research priorities. Fearful of excluding the other research foci by proposing a single integrated focus, they presented a generalized approach to the zebra mussel research priority problem. They stated that research priorities can be identified by using the six previously defined research foci and ranking elements produced during the framework exercise. This approach should be an iterative process that can be used to identify specific research projects as needed.

The *Stakeholder* perspective emphasized their interests and viewpoints to ensure that their concerns are not ignored or forgotten in the priority establishment process. Rather than preparing a statement of research priorities, they commented on a number of the most highly valued elements. Stake-holders gave a low ranking to the issue of nutrient and contaminant cycles because they are unimportant unless the zebra mussel manifests itself in algae blooms or reduced water clarity. The identification of potential invaders received a medium priority ranking. The remaining elements were rated highly for a variety of reasons. Shipping and navigation should be a high priority because they have already been substantially impacted and further costs should be avoided. Determination of preventive measures is important because stakeholders are not prepared for future unexpected events. Physical measures are of high priority to stakeholders because they are non-chemical and may provide alternatives to the disruption of non-targets. Finally, stake-holders were highly concerned about the consequences of control. They call for an evaluation of trade-offs between the minor consequences of immediate action versus the long-term damage of no action.

Other than the social scientists who adopted a much broader interpretation of the establishment of research priorities, the perspective groups accepted the new research focus as a means of setting research priorities for zebra mussel research in Lake Erie. Although each perspective presented the new focus and ranked elements according to their particular interests, a consensus was adopted on the process used to determine priorities and the content of the newly favoured research focus.

3.2.2 Wetlands

The International Joint Commission, in assigning priorities to the Council of Great Lakes Research Managers, determined that there should be a workplan element on wetlands as part of the priority on "Impacts of Changes on the Lake Erie Ecosystem." The Commission noted that approximately two-thirds of the original wetland areas of the Great Lakes basin have been destroyed, and that wetlands play an important role in maintaining healthy fish and wildlife populations and desirable water quality and quantity. The most recent report on the State of the Lakes noted that, notwithstanding the efforts of individual agencies over several decades, in some cases, to delineate these wetlands, a common comprehensive binational map has yet to be developed. Thus the extent of basinwide wetland loss can only be implied through anecdotal evidence.

Identification and preservation of wetlands is mentioned twice in the Great Lakes Water Quality Agreement. Annex 13 of the Agreement is concerned with pollution from nonpoint sources and section 3 of the annex states that significant wetland areas in the Great Lakes system that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated. Similarly, Annex 17 of the Agreement states that the Parties shall determine the aquatic effects of varying lake levels in relation to pollution sources, particularly respecting the conservation of wetlands and the fate and effects of pollutants in the Great Lakes Basin Ecosystem in accordance with Annexes 2, 11, 12, 13, 15 and 16. These two references provide the context for the involvement of the International Joint Commission in the evaluation of the technology for surveillance of the status of wetlands.

As explained elsewhere in this report, this wetland priority was included for consideration in the design of the Lake Erie model. The following report describes some of the recent advances in research and development, particularly the remote-sensing technology being applied to survey wetland habitat in the Great Lakes basin, with particular reference to studies that have been undertaken on the extensive wetlands in the delta of Lake St. Clair. Staff of the Great Lakes Regional Office of the International Joint Commission worked in collaboration with scientists and technologists from the Remote Sensing Satellite Ground Station of the Chinese Academy of Sciences in Beijing, the Canada Centre for Remote Sensing, and Intera Information Technologies in Ottawa, and the Department of Geography of the University of Windsor (Li et al. 1995).

The two systems that were compared were both satellite mounted. One of the systems is the Landsat Thematic Mapper which senses seven bands at optical and infrared wavelengths. The second system is the Synthetic Aperture Radar, which is operational through cloud cover and thus can theoretically be used in all weather, was carried on the Earth Resources Satellite-1. Data from these two systems are received in a digital format. Because the Thematic Mapper, as a passive receiver, cannot operate through cloud cover, data from the weather reporting station at Wallaceburg were obtained to assist in the selection of the specific dates, between May 1992 to April 1993, on which the satellite data were obtained. Two sets of data were acquired for the Thematic Mapper, using three wavelengths. Ten sets of data were used from the Synthetic Aperture Radar.

The following seven classes of land cover were identified in the delta of Lake St. Clair, from topographic maps and aerial photographs: urban; forest; agriculture; cattail marsh; phragmites wetland; swamp; and open water. Seven areas, representing each of these classes, were chosen for calibration of the radar data and comparison with the data from the optical sensors. These data comparisons from the two different systems were made using data for locations that had been verified precisely to be the same. The ten sets of radar data were analyzed using principal component analysis to display the information as a single channel for machine classification or the interpretation of images. Prints of the images generated from these various kinds of data processing were used for laboratory analysis and to compare with the actual land cover observed during field visits.

The results showed that both systems are reliable bases for classifying land cover in the delta of Lake St. Clair, and the two data sets were better than either alone. Best results were obtained when weather conditions were warm and dry and during the season of active plant growth. With the radar system the response over agricultural land was influenced by whether or not there was a crop and whether the bare ground was dry or wet. Images from radar data collected in March for urban and forest areas, and in June of phragmites grass and cattails, could not be distinguished. The resolution of the various categories of land cover is poor under freezing weather conditions and decreased with rain, and the separation of the boundary between the vegetation and the water is obscured under windy conditions.

The use of satellite-mounted remote sensing has proven to be a reliable system for classifying land use for almost two decades. Data from the system best distinguish the various classes in the spring. For example, swamp and phragmites marshes have similar images in the fall but can be reliably distinguished in June. The best results were obtained using two wavelengths of the optical system combined with the radar data after it had been transformed, using principal component analysis and printing of the image in a false colour composite as shown in Figure 3. There are several advantages to the application of this technology. First, it can be used to integrate data using common criteria across jurisdictional boundaries. Second, it is capable of using different resolutions to yield comprehensive or selective coverage on a geographic or temporal basis. Finally, it provides the ability to respond in a relatively short time period. The project has demonstrated that this technology could be used by the Parties to the Great Lakes Water Quality Agreement and jurisdictions in a common binational evaluation of the status of wetlands and other land uses in the Great Lakes basin.

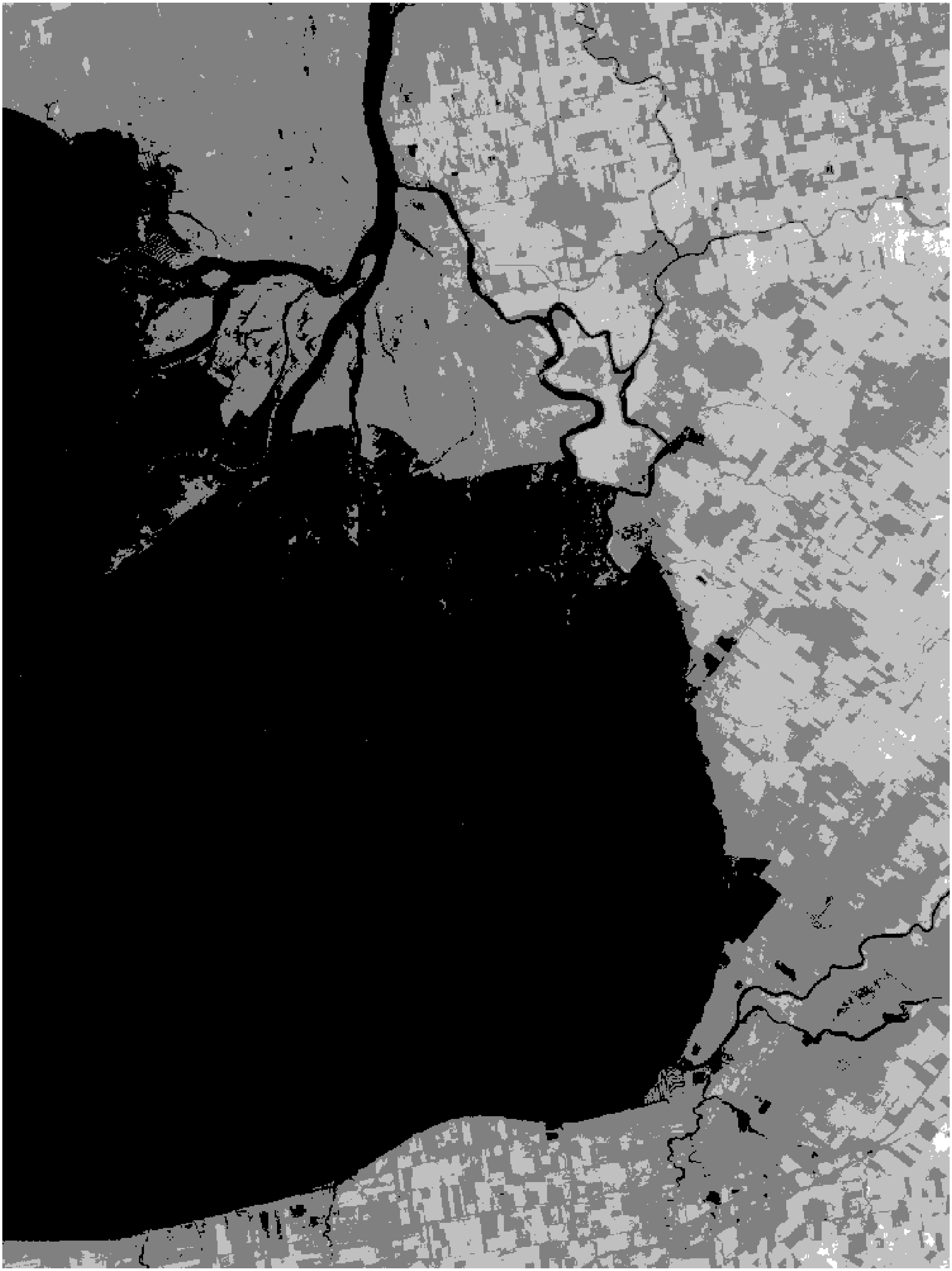

Figure 3.
Satellite Mounted Remote Sensing System Results Composite Image of St. Clair River Delta and Lake St. Clair from Satellite (ERS-1) Remote Sensing
Source: Canada Centre for Remote Sensing, Geomatics Canada, Ottawa, Ontario

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3.3 Vision Workshop

The Council of Great Lakes Research Managers held a vision workshop on February 21 and 22, 1995 in Windsor, Ontario to review progress on the Council's agenda, which had been developed at a previous vision workshop held in Niagara-on-the-Lake in 1989, and to develop a new agenda for the period 1995-2000.

Workshop participants reviewed some of the achievements of the Council since the 1989 workshop. The Council was instrumental in focussing the attention of the Parties, and the International Joint Commission, on the need to investigate the implications of the introduction of zebra mussels and quagga mussels into the Lake Erie ecosystem. The Council has developed an Ecosystem Framework to link research on natural systems to the socio-economic and political systems, and applied this framework to the ranking research priorities and policy options concerning the introduction of exotic species generally and zebra mussels in particular.

The Council published a Research Inventory in 1990-91 and 1991-92 that detailed the research undertaken to investigate the Great Lakes and prepared a report on indicators of ecosystem integrity, which was published in 1991.

At the February 1995 Vision Workshop, the Council reviewed its Terms of Reference. It recommended that the terms should be broadened to promote communication, co-operation, collaboration and coordination between researchers and agencies, and encourage the review and integration of research results and their transfer to policymakers, resource managers and the public.

The Council members identified the following five priority areas for future action planning by the Council:

Communications and Education

> The responsibility of scientists to inform and involve our citizenry about their work and results is paramount, particularly when there are serious ethical dilemmas which need to be resolved. Given this backdrop, areas where scientists cannot agree could be identified, with the implications for the future as a basis for informed public debate. There is a clear role for the Council in leading the identification, development and promotion of common protocols and standards for conducting research between the various jurisdictions. Meetings of the Council could be used to share priorities and program results with members and public interest groups. The addition of socio-economic disciplines to its membership would enhance the ability of the Council to deliberate in a multidisciplinary and perhaps interdisciplinary manner. Operationalizing the Ecosystem Framework would go a long way toward implementing Council's communications and education priority.

Evolving Trends

> Reiteration of the need to focus on research that ensures compliance with the Great Lakes Water Quality Agreement and the 14 use impairments is stressed. In particular, the effects of the following four trends on determining the Great Lakes research agenda need consideration: the effect on the professional development of Great Lakes research scientists as a result of U.S. federal policy to use inhouse researchers; the effect of the U.S. federal trend to shift activities toward the states, and the local level may result in a narrowing of focus away from basinwide research; the weight given to the use of risk assessment and public interest group agendas in determining research priorities; and the magnitude of the threat of endocrine disrupting compounds.

Organizational Issues

The promotion of collaborative interjurisdictional and interdisciplinary research planning is considered to be of paramount importance. Pooling of talent and resources of the Council's member organizations as a collaborative model and learning experience could identify ways of overcoming existing barriers to achieving this goal.

Research Review

Over the next five to ten years, the review function of the Council is expected to expand considerably. This is partly due to the broad research scope involved in implementing sustainable development and ecosystem management practices. When coupled with the continued limiting of human resources and research funds, the Council envisages that a direct benefit will be realized when selecting new research activities and when planning for the continuation of projects. The Council identifies the need for a blend of strategic, basic, priority and applied research in fulfilling the mandate in Annex 17. The continued assessment of the effectiveness and impact of research is expected to become more and more necessary. A strategy to identify criteria that will determine what is reviewed will be necessary.

Sustainable Development

Sustainable development as a concept will need to be translated into actionable research programs. To address this gap, the Council needs to facilitate the assessment of research to determine its relevance to sustainable development. A major contribution of the Council could be to develop a "Sustainable Development Roadmap." An examination of the Parties' role in sustainable development, emphasizing research aspects of certain selected projects such as the Lake Superior Binational Program, the Hamilton Harbour and Remedial Action Plans would assist in implementing this widely embraced concept. Identifying links between sustainable development in the application of the ecosystem approach would be a substantial contribution to research managers. The Council is committed to incorporating the priority of sustainable development into the four key areas of the Council's work, namely: Communications and Education, Organizational Issues, Evolving Trends and Review.

Results of the Council's deliberations were organized by objective, in order of priority. The following section identifies the actions to be undertaken by the Council, subject to Commission approval, arranged in relation to its terms of reference, with proposed features in italics. Collectively, they make up what the Council has termed Achievements 2000: The Council's Vision.

Objective #1: Promote communications, cooperation, collaboration and coordination between researchers, agencies and Parties in addressing IJC priorities. Specifically the Council will encourage the promotion of interjurisdictional and interdisciplinary planning and coordination of research related to the implementation of the GLWQA.

Action 1:

Dissemination of research results to public and educators

Action 2:

Improve effectiveness of research coordination

Action 3:

Lake Erie Ecosystem Model - Phase 2

Action 4:

Operationalize the Ecosystem Frame work

Action 5:

Presentations on priority research issues at Council meetings

Action 6:

Improve communications within the Council and the research community

Action 7:

Review Council membership

Objective #2: Encourage preparation and dissemination of syntheses of research findings to government and nongovernment bodies concerned with Great Lakes management *through the systematic reporting of results through common planning and reporting mechanisms*; and bring policy implications of the aforementioned findings to the attention of the recipients.

Action 1:

Foster mechanisms to synthesize research data sets to assess long-term trends in the Great Lakes (e.g. persistent toxic substances)

Action 2:

Establish a Home Page on the Great Lakes Information Network and World Wide Web

Action 3:

Create opportunities for public input to the research agenda and priorities

Action 4:

Foster methods to develop data standards and protocols, to achieve standardized data sets for specific initiatives.

Objective #3: Compile and summarize current and planned research programs related to the implementation of the GLWQA; *assess the adequacy of the Parties research programs relating to the GLWQA and Annex 17; and promote the transfer of research findings to basin policymakers, resource managers and the public.*

Action 1:

Assess the research inventory to identify its usefulness and the potential willingness of users to pay for the inventory

Action 2:

Subject to action 1, update and maintain the inventory, publish the inventory on GLIN and produce printed version

Action 3:

Assess, analyze and evaluate research programs, recommend steps to fulfil unaddressed mandates

Objective #4: Identify research needs; establish priorities and *identify gaps and* encourage the Parties to make the maximum effort to shift funding towards directly relevant studies to the GLWQA s purpose.

Action 1:

Establish a formal process and strategy to identify top research priorities

Action 2:

Develop a white paper and conduct a workshop on Sentinel Event Reporting

Action 3:

Develop a white paper and conduct a workshop to assess factors used by the Parties in establishing research agenda (with particular focus on the role of risk assessments and public interest groups)

Action 4:

Develop a strategy for Council review of ongoing research to determine if ecosystem approach and sustainable development goals are being achieved

Objective #5: Keep under review the impact of research recommendations made by itself, the Great Lakes Science Advisory Board, the Great Lakes Water Quality Board and the Commission.

Action 1:

Establish Evolving Trends Subcommittee of the Council and liaise with the Science Advisory Board's Workgroup on Emerging Issues

Conclusions

As the Great Lakes research community moves towards the year 2000, continued care needs to be taken to ensure that the limited resources are directed towards scientific and management priorities.

The aspirations of our individual members are reflected in the Council's ongoing commitment to ensuring the continued improvement of the health of the waters and ecosystem of the Great Lakes basin. Our action plan is pragmatic and cost effective and will ensure the progress continues to be made in understanding the Great Lakes system so that important management decisions can be made.

"Achievements 2000: The Council's Vision" is optimistic, even in these uncertain times. We recognize the importance of the ecosystem approach to Great Lakes management, thus the framework which we developed. However, we reiterate and emphasize the importance of pursuing substantive research actions to understand, document and effect the virtual elimination of priority persistent toxic substances. Our progress towards achieving sustainable development must be more clearly understood. A testament to the Council's role in this area is the work we initiated with the Lake Erie prototype model, which is a significant effort to understand the changes in the Lake Erie basin, and to influence a management framework which achieves *sustainability*.

We must take advantage of new communications technology to improve our dialogue, debates and discussion, particularly between scientists and managers. These actions are simple, yet effective.

Our review of the past five years, our Terms of Reference and our aspirations reveal our unanimous view that the Council has a fundamentally important role to play in ensuring closer integration between science, managers and public interest groups; that our research agenda is developed on a collaborative, priority basis; and that checks and balances continue to occur to ensure relevance. Our track record over the past five years is indicative of the considerable results which can be achieved through this outstanding example of bilateral, multijurisdictional collaboration.

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