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Remedial Action Plan Research Needs

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International Joint Commission. Great Lakes Regional Office

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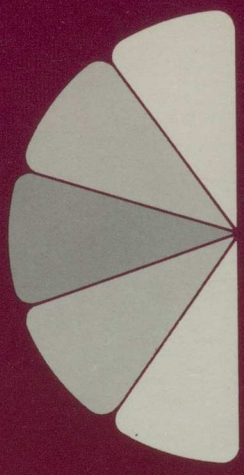
International Joint Commission
Council of Great Lakes Research Managers



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International Joint Commission
Council of Great Lakes Research Managers

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REMEDIAL ACTION PLAN RESEARCH NEEDS
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Canada

Canada Center for Inland Waters - National Water Research Institute
Environmental Protection Service
Canadian Wildlife Service
Inland Waters Directorate
Great Lakes Laboratory for Fisheries and Aquatic Sciences
Ontario Ministry of the Environment
Ontario Ministry of Natural Resources

United States Organizations

NOAA - Great Lakes Environmental Research Laboratory
U.S. Fish and Wildlife Service

International

International Joint Commission - Great Lakes Regional Office.

Finally, the Steering Committee wishes to acknowledge P. Murray for her assistance in the preparation of this report.

DISCLAIMER

This report to the Chairpersons of the Science Advisory Board and International Joint Commission was carried out as part of the activities of the Council of Great Lakes Research Managers. While the Commission supported this work, the specific conclusions and recommendations do not necessarily represent the views of the International Joint Commission, the Science Advisory Board or its committees.

Forward

Remedial Action Plan Research Needs

The International Joint Commission has requested the Council of Great Lakes Research Managers to "identify research needs and establish priorities." The Council, consisting of 18 heads of laboratories or funding agencies, meets at least twice annually to plan and coordinate research related to the Great Lakes Water Quality Agreement. Our terms of reference allow us to establish task forces and request the assistance of experts.

At the Council's August 1987 meeting, we decided that it would be appropriate for the Council to issue a synopsis of the required research needs for Areas of Concern given that Remedial Action Plans for Areas of Concern were under preparation. A Committee was formed and immediately met with the aim of quickly preparing a draft document for discussion at the forthcoming biennial meeting of the International Joint Commission which was to be held in November 1987 in Toledo, Ohio. It was anticipated that a new Annex would be introduced into the 1987 Protocol to the 1978 Great Lakes Water Quality Agreement to respond specifically to the preparation of Remedial Action Plans for Areas of Concern.

The Committee of Canadian and United States scientific experts met and collectively prepared an outline of the overall themes to be contained in the report on Research Needs for "Areas of Concern" sections of the report, collectively reviewed these, and agreed upon the general approach to be taken for a final report. All areas of research could not, of course, be represented on the Committee because of the diversity of the issues in Areas of Concern. The Committee thus approached scientific colleagues in both the United States and Canada to comment on the draft report and to add or alter sections as required or requested. These submissions were subsequently reviewed and edited by the Committee and incorporated into the report. The initial report was thus prepared rapidly and was based on the collective wisdom of a large number of research experts with many years experience in the Great Lakes.

This draft of the report was then widely distributed to all Remedial Action Plan Coordinators and their comments sought as to omissions. Some Coordinators attended a subsequent meeting of the committee to present their views and these and all comments received in writing were taken into consideration in the preparation of the penultimate draft. These activities were completed on schedule so that the Report on Research Needs in Areas of Concern could be presented in overview to the Remedial Action Plan Coordinators Public Workshop held immediately after the IJC Biennial Meeting in Toledo. All comments from the audience at the Workshop were taken into consideration in the preparation of the final draft of the report submitted by the Committee to the Council of Research Managers. Thus, all coordinators and others who attended the open Toledo Workshop, were solicited for views and comments and all responses were incorporated into the final draft submitted by the Committee to the Council of Research Managers.

Nevertheless, it was clear to the Committee and to the Council that not all research aspects were covered in equal detail. In particular, two research areas which require greater in-depth analysis, not only for Areas of Concern but for the Great Lakes basin in general, are the cause-effect linkages between toxic chemical pollution of the lakes and human health aspects and the socio-economic aspects of implementing Remedial Action Plans. The former will be the subject of a Council of Research Managers Workshop planned for 1989. The latter may require a new initiative by the Science Advisory Board. The Council is releasing this report as an aid to Remedial Action Plan Coordinators, as a resource document for the forthcoming Workshop on Cause-Effect Relationships, and as a stimulus of the need for the Great Lakes community to place great emphasis on the socio-economic aspects of pollution abatement.

David Egar, Canadian Co-Chair
Jon G. Stanley, U.S. Co-Chair
Council of Great Lakes Research Managers

INTRODUCTION

Forty-two Areas of Concern have been identified in the Great Lakes basin; in these areas the 1978 Great Lakes Water Quality Agreement objectives or jurisdictional (state/provincial) standards, criteria or guidelines have been exceeded (Figure 1). As a result of the 1985 Report of the Water Quality Board, the eight Great Lakes States and the Province of Ontario committed themselves to developing a remedial action plan (RAP) for each Area of Concern within their political boundaries. RAPs will not only identify specific measures to control sources of pollution, abate existing contamination (e.g. contaminated sediments) and restore all uses, but will also present schedules for the implementation of specific remedial actions.

There are a number of research topics which must be addressed before Areas of Concern can be fully restored. One of the major goals of the Council of Great Lakes Research Managers (CGLRM) is to identify RAP research needs. To attain this goal, the CGLRM established a "Research Needs Steering Committee" to develop a document detailing research and study needs. This document was to aid in RAP development and to help establish the need for funding research.

The steering committee made numerous enquiries within the Great Lakes basin to assist in identifying research topics specific to Areas of Concern. A questionnaire addressing research needs was sent to all RAP coordinators and the information received from them was used to compile this document. It represents a compilation of the RAP research needs identified by scientists active in Areas of Concern, the Research Needs Steering Committee and jurisdictional RAP coordinators. Because of the various research requirements specific to the individual Areas of Concern, no attempt was made to assign priorities to research and study needs.

The assessment and subsequent remediation of problems in Areas of Concern is generally a difficult task. Understanding the complex physical, chemical and biological interactions which characterize river mouths and embayments frequently involves considerable effort. A good understanding of these complex systems is a prerequisite to developing an effective RAP, particularly if *in situ* remediation is necessary. The following outline developed by the Research Needs Steering Committee is designed to identify current research and study needs which would aid in the development of an effective remedial action plan. The outline identifies six categories (i.e. Ecosystem Assessment, Ecosystem Interactions, Sources/Transport Pathways, Source Control, *In Situ* Remediation, and Socioeconomic Considerations) into which the RAP research and study needs were grouped (Figure 2).

This document has primarily addressed RAP research and study needs relating to the physical, chemical and biological sciences. In addition to the research needs identified for ecosystem integrity (water, sediments and biota), socio-economic considerations need to be addressed in developing an implementable remedial action plan. Socio-economic considerations include identifying the institutional, economic and personal behaviours which promote environmental degradation. Furthermore, the costs of remedial options and their social impact must be addressed in order to determine the final strategy. The Societal Committee of the IJC's Science Advisory Board is currently addressing these issues. Therefore, only a general outline of the social and economic research needs for RAPs is included in this report.

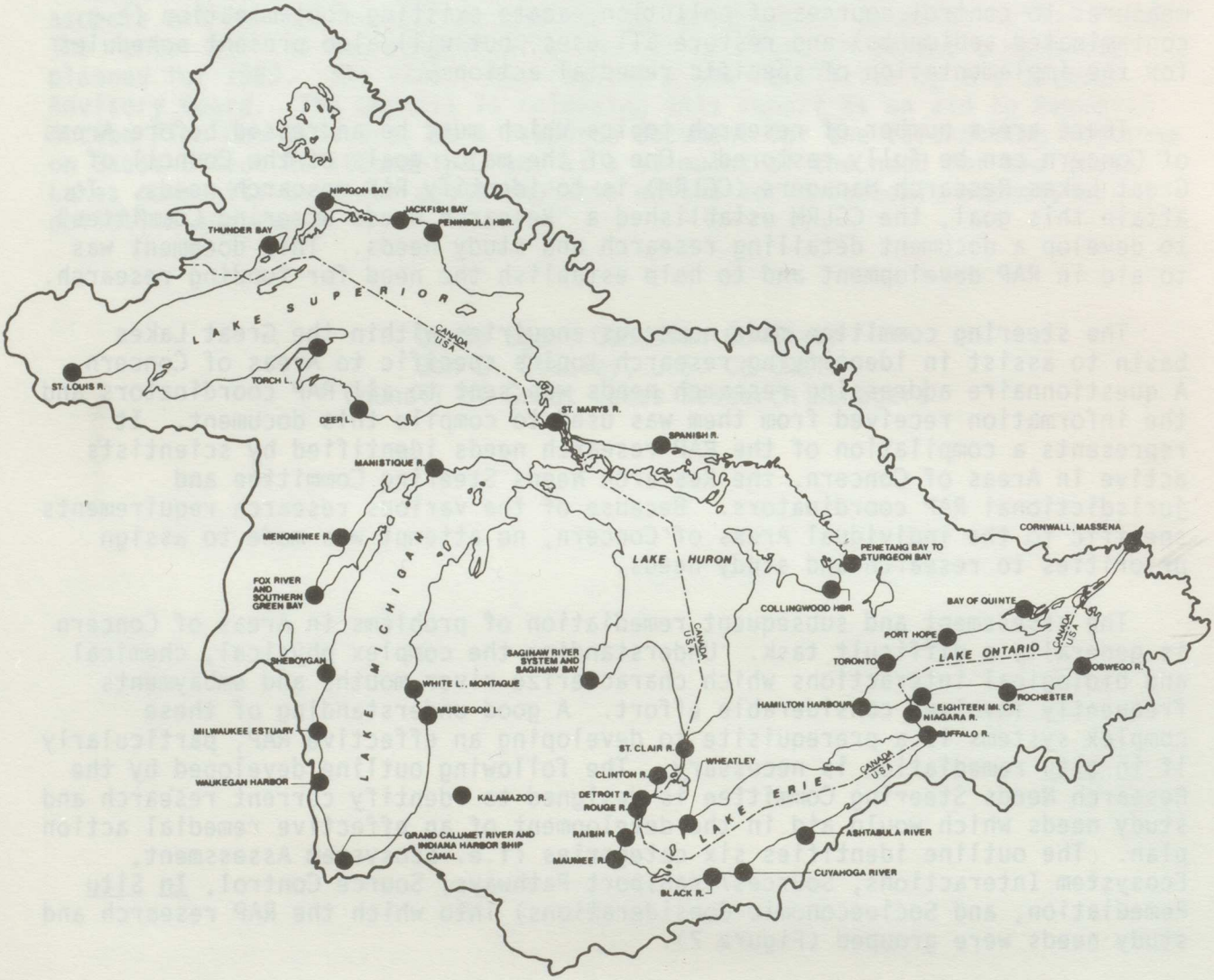


FIGURE 1 - AREAS OF CONCERN IN THE GREAT LAKES

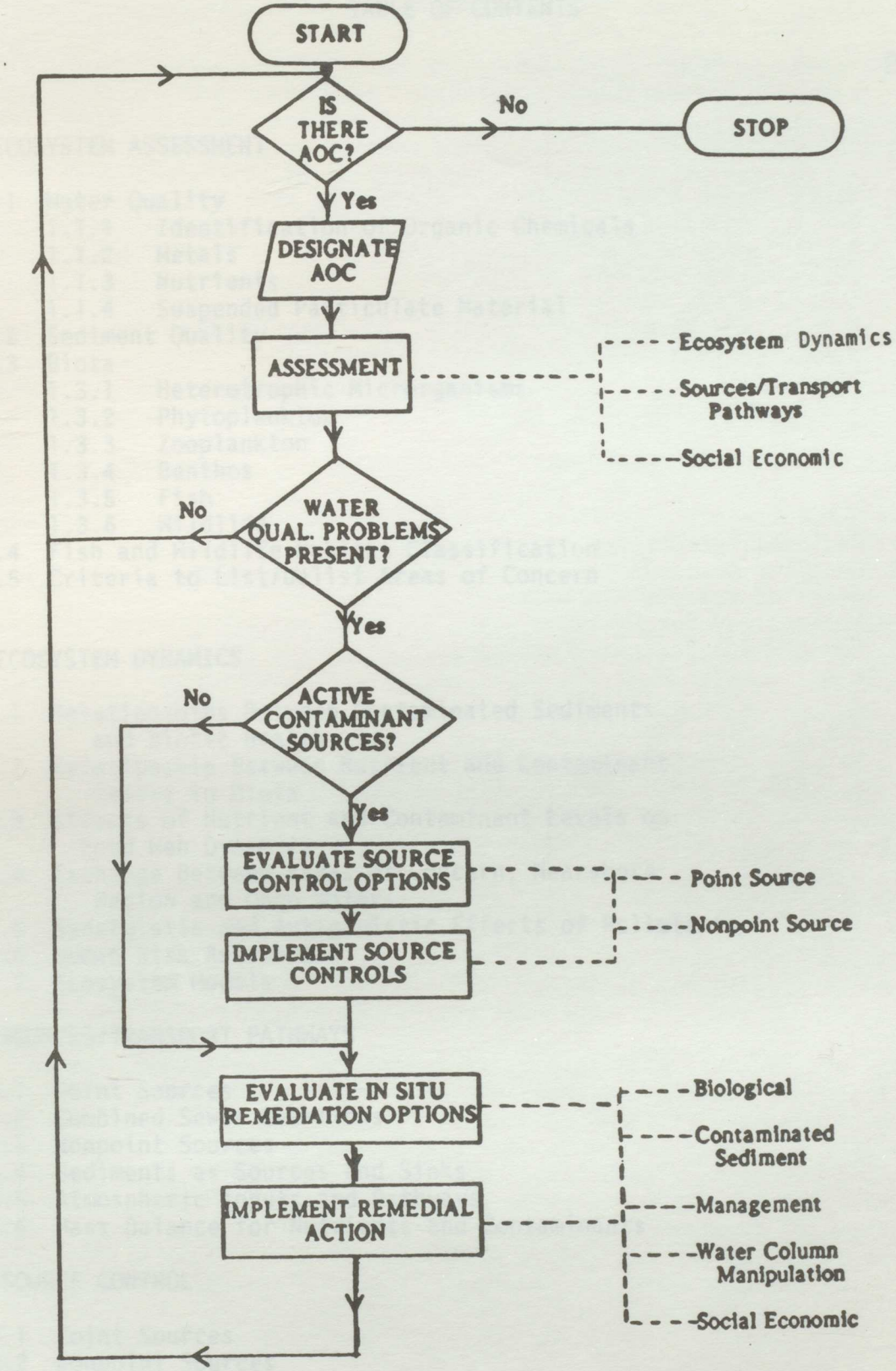
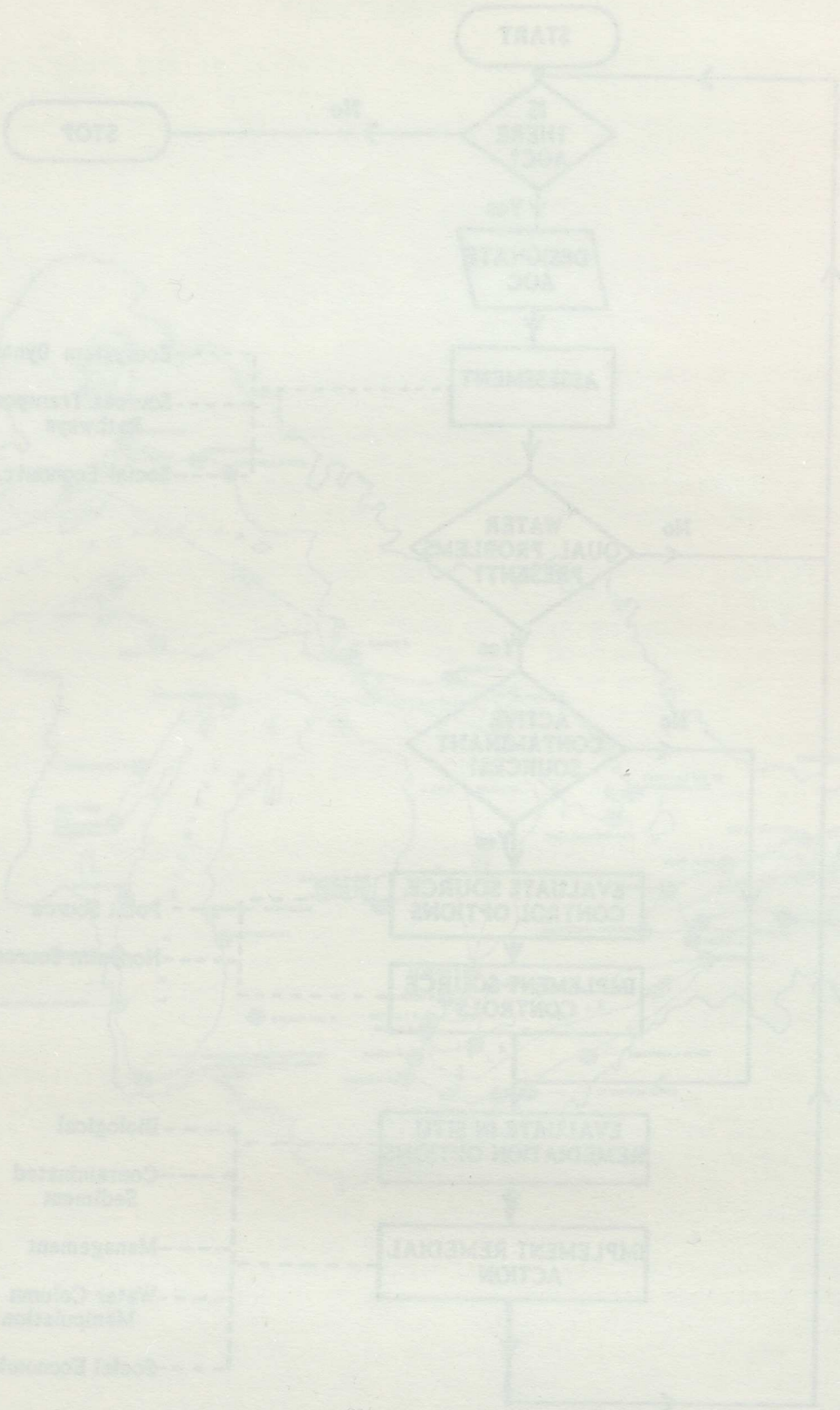


FIGURE 2. FLOW DIAGRAM FOR PROPOSED AREAS OF CONCERN RESEARCH NEEDS



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1.0 ECOSYSTEM ASSESSMENT

The classification of 42 locations in the Great Lakes as Areas of Concern indicates a substantial data base identifying contamination. However, the available data are often not sufficient to quantify the degree and extent of contamination. There are also cases where additional water quality and ecosystem objectives need to be developed. The basic requirement for designing a remedial action plan (RAP) and judging its success after implementation is the accurate measurement of current and future characteristics, and if possible, the reconstruction of trends since settlement.

This chapter recommends research activities that should be initiated to assist the assessment studies being undertaken by all agencies. Ecosystem components are discussed separately under water quality, sediment quality, biota, fish and wildlife classifications, and criteria to list/delist Areas of Concern.

1.1 Water Quality

1.1.1 Organic Chemicals

To identify and measure chemical substances in water is an important first step in evaluating the nature and extent of pollution, and is essential for the formulation of effective remedial and control measures. Although there are several methods currently used, the most common one for site characterization involves analyses of target "priority" compounds. This method is used because the analytical techniques are readily available and the results can be obtained relatively quickly. However, this approach has some severe limitations. The results are heavily biased in favour of compounds that are readily detected using selective detectors. In sites with numerous potential sources, characterized by less easily detectable compounds, it is ill-advised to attempt to characterize the total distribution of pollutants using such selective analyses. Thus, to propose remedial and control measures based exclusively on these limited characterizations is not recommended. There is a need to continue research into developing new methods which would aid in identifying previously undetected compounds.

The most comprehensive method currently available involves the analysis of extracts by gas chromatography-mass spectrometry (GC/MS). In practice, this method is not routinely applied because to identify unknowns from their mass spectra can be time consuming, and some compounds cannot be analyzed by gas chromatography. The technique can be significantly augmented through the use of computerized data bases containing mass spectra libraries. Existing libraries, however, are inadequate for the purpose. Research is needed to more efficiently apply currently available techniques and to devise new techniques for the identification of compounds currently undetected.

Research should:

- Identify, using GC/MS and other techniques, contaminants representing all the major chemical groups in Areas of Concern. This activity includes the synthesis of compounds tentatively

identified to confirm identities and determine properties, such as mass spectra, for inclusion in computerized data bases

- Develop novel approaches to chemical characterization such as liquid chromatography-mass spectrometry (LC/MS) and gas chromatography infrared spectrometry (GC/IR) to further aid in identifying and characterizing contaminants

- Develop protocols to screen and assign priorities (e.g. based on persistence, biological activity or toxicity) to samples for contaminant characterization in order to more efficiently utilize laboratory resources

1.1.2 Metals

Some dissolved trace metals, depending on the concentration, can be stimulating or toxic to biological entities. For most trace metals the concentration range of stimulation is usually low and narrow; for others it has only detrimental effects. Unfortunately, reliable metals data do not exist for many Areas of Concern. The contamination of samples, which may occur at any point from collection to analysis, is responsible for the questionable data quality characterized by most routine monitoring schemes. Further research is required to establish reliable in situ concentrations. Complicating the uncertainty about total metal concentrations is the necessity to identify the metal species in order to predict the mode of interaction between metals, on the one hand, and biota and geochemical cycles on the other.

Research should:

- Develop and validate procedures for sampling metals that prevents sample contamination

- Develop methods to analyze metals at the anion/cation level, in addition to total concentrations, in order to establish bioavailability

- Identify and quantify mechanisms controlling dissolved metal concentrations in the different types of Areas of Concern

- Quantify methylation and demethylation rates of arsenic, mercury, selenium and lead in the water column and their release rates to the atmosphere

- Quantify the acceptable concentration ranges for biologically essential trace metals such as selenium, molybdenum and cobalt

1.1.3 Nutrients

Nutrient loading and ambient concentrations affect primary production while the ratio of major nutrients (nitrogen and phosphorus) influences algal species composition and succession. These two factors (loading and ratio) can have significant influences on the structure and functioning of higher trophic levels. Although the relationship between nutrients and the response of the phytoplankton community in lakes is generally understood, the extent to which the response to changes in loading can be predicted is not precise. This

shortcoming is particularly true in Areas of Concern characterized by hypereutrophic and highly variable responses from both the planktonic and benthic algal communities.

Three major issues concerning nutrients need definition. First, the methodology for assessing trends in nutrient concentration in highly variable systems such as Areas of Concern is not fully developed. Second, the quantitative relationships between nutrients and biological responses are not precise enough to develop detailed management plans. Third, the relationship between biological responses, triggered by nutrients, and water use criteria are not well defined. Consequently, the establishment of water quality objectives with respect to nutrients is not straightforward.

Research should:

- Develop the relationships between nutrient loading, ambient concentrations and biological response
- Develop statistical procedures to adequately track changes in ambient nutrient concentrations, where a high degree of variability is encountered
- Analyze the effect of variable loading functions on the spatial and temporal scales of concentration responses in different classes of Areas of Concern (i.e. large embayments and rivers/harbors)
- Investigate the bioavailability of nitrogen and phosphorus associated with suspended material originating from nonpoint (tributaries) and point sources

1.1.4 Suspended Particulate Material

The quantity and type of material suspended in the water column affects water clarity, fish ecology (feeding, spawning and rearing), macrophyte growth and development, algal growth and succession, and the cycling of metals and organic contaminants. The extent to which suspended materials are derived from the drainage basin, from resuspension of in situ sediments or from production in the water column (e.g. $CaCO_3$ precipitation, algal flocs) is often unquantifiable. Frequently, the only long-term data on water clarity is from Secchi disk measurements which cannot in themselves be used to determine the specific contributing components. Establishing long-term trends and factors affecting changes in transparency is not possible without ancillary data.

Research should:

- Establish the influence of suspended inorganic and organic material, water colour, plankton cell or organism number and size on water clarity and light absorption
- Establish turbidity guidelines which reflect the nature of the suspended material and the water colour to ensure the level of water clarity needed to accommodate a variety of uses (i.e. swimming, macrophyte bed development)

- Design sampling networks to adequately measure the intermittent introduction of suspended material into the water column via tributaries, shore erosion and resuspension

1.2 Sediment Quality

Contaminated sediments have been identified as a problem in 41 of the 42 Areas of Concern. Sediments continually interact with the overlying water, acting as sinks for contaminants, but more importantly, they can also serve as a secondary loading source through physical, chemical and biological processes. Although quantitative estimations of sediment contaminant levels can be made, the processes by which sediments receive and/or release other components of the ecosystem are not well understood.

Sediment chemistry is complex; sediments contain a mixture of elements, minerals and products of biochemical degradation from both aquatic and terrestrial biota and from soils as well as contaminants added through anthropogenic activities. Chemical analysis is necessary to assess sediment quality, but it is not generally sufficient to provide an ecosystem assessment due to the complex interactions from all the components. Consequently, bioassay techniques are also required and are discussed in subsequent sections.

Specific research should:

- Establish protocols for relating sediment contaminant concentrations to characteristics such as grain size, porosity, cohesiveness and organic content

- Develop a means for assessing the susceptibility of varying sediment types to resuspension and for determining the processes and factors affecting resuspension

- Examine the relationship among various chemical species and concentrations in sediments, the water column and biota, and determine the factors which affect these relationships

- Develop and validate bioassay criteria and protocols that utilize species indigenous to the Great Lakes ecosystem

1.3 Biota

1.3.1 Heterotrophic Microrganisms

The microbiological concerns considered in this section are related to ecological considerations and not to issues associated with public health, such as disease transmission or beach closures. The microbial community plays a crucial role in nutrient/contaminant recycling, regeneration, degradation and detoxification. The metabolic processes involved, however, are poorly understood. Other than compliance monitoring for public health, metabolic pathway and rate information is rarely obtained. Consideration of the role these organisms play in the ecosystem and their potential importance in the recovery of highly contaminated regions should lead to greater emphasis on understanding their effect on specific regions.

Research should:

- Establish protocols to assess microbial population dynamics
- Develop techniques for assessing the activity level of specific heterotrophic groups which are responsible for nutrient and contaminant cycling
- Quantify the factors which control beneficial microbial processes and investigate the techniques to enhance metabolic rates in situ (e.g. nitrification)

1.3.2 Phytoplankton

Phytoplankton and periphyton are major primary producers. Productivity, life cycles and succession may be affected by contaminants, nutrients and suspended materials, which can in turn effect the overall ecosystem health. The effect which phytoplankton community structure and biomass have on water quality and other organisms is also an important consideration in the development of remedial action plans.

A great deal of variability is associated with algal population dynamics in Areas of Concern, where stimulation via nutrients or depression via contaminants and suspended material can occur simultaneously on overlapping gradients. Even measuring algal biomass and species composition on a seasonal basis requires frequent and dense spatial sampling grids.

Research should:

- Establish the effect of suspended material, water colour, phytoplankton cells and organic detritus on the light climate for primary producers (i.e. factors affecting extinction coefficients)
- Compare and contrast phytoplankton and periphyton community structure and succession in Areas of Concern with those in unpolluted areas of the Great Lakes basin
- Establish the factors and processes which promote the growth and/or inhibition of phytoplankton and periphyton
- Develop and test physiological indicators of phytoplankton stress due to specific contaminants and mixtures

1.3.3 Zooplankton

Because zooplankton can be major consumers of organic matter synthesized by the primary producers, as well as allochthonous organic inputs, the species composition and productivity of zooplankton populations may have major effects on phytoplankton succession and productivity. In addition, the uptake and storage of contaminants from food particles by zooplankton can be an important transfer mechanism to fish, wildlife and sediments. Defining the species composition and their interactions with other trophic levels is difficult due to the steep and overlapping chemical/physical gradients. These dynamic gradients keep zooplankton populations in a state of disequilibrium, thus making population dynamics predictions difficult.

Research should:

- Identify the species which are responsible for the greatest transfer of contaminants from primary to tertiary trophic levels

- Investigate the structure and functioning of zooplankton communities residing on steep contaminant and physical/chemical gradients

- Establish the importance of flagellated and ciliated protozoans and phagotrophic heterotrophs in the transfer of contaminants through the food chain

1.3.4 Benthos

Currently, several initiatives are proposing to use benthic community structure to assess the significance of toxic contaminants in sediments. Emphasis is being placed on benthic invertebrates both for problem confirmation and detailed assessment. However, responses in the benthic invertebrate community to toxic contaminants, unlike the responses to organic enrichment, are not well understood. Consequently, research is necessary to determine the response of the benthos to toxic contaminants and other environmental variables.

Research should:

- Develop relationships between the structure of benthic communities and the physical/chemical characteristics of sediment using both open lake control sites and Areas of Concern

- Conduct mesocosm manipulations to observe changes in community structure in relation to toxic stress

1.3.5 Fish

Knowledge of fish community structure, including species abundance, diversity and age-class distribution, is fundamental to evaluating and managing the resource. In addition, identifying specific indicators of stress, such as the incidence of tumours and mixed function oxidase levels is required in order to link <u>in situ</u> contaminant exposure with remedial options. Incomplete information on these issues has been ascribed primarily to problems in methodology which require research to resolve.

Research should:

- Establish statistically sound, uniform protocols for estimating total body burdens for contaminants in resident fish species

- Establish the incidence of toxic stress indicators (e.g. tumors and low fecundity) in clean and contaminated environments

- Determine the causative agents and establish the dose/response relationship for the various indicators of stress

- Develop methods to measure sub-lethal and chronic effects

- Establish whether fish populations are limited by habitat or food in Areas of Concern

1.3.6 Wildlife

Aquatic wildlife are severely restricted in Areas of Concern because of the scarcity of appropriate uncontaminated food and rearing habitat. Information concerning the natural assemblages in these areas is generally undocumented because the drainage basin and nearshore zones were often dramatically altered even before contaminants were recognized. This situation has lead to a limited assemblage of resident wildlife or to temporary migrants currently occupying small niches in the system. Residents now serve as indicators of environmental pollution (e.g. gull egg monitoring). The extent to which a particular Area of Concern has contributed to the contamination of resident wildlife is often not quantifiable.

Wildlife (birds and animals) species that are affected by extreme exposure to toxic substances and/or particularly susceptible to them are referred to as "critical species". Several wildlife species throughout the Great Lakes basin have been seriously impaired by persistent toxic substances via contaminated food chains. For example, trapping records indicate that mink and otter populations near Lake Ontario and Lake Michigan have declined and no longer support viable harvests despite the presence of suitable habitats. Their absence from these locations has been attributed to high PCB levels. Both dioxins and furans, however, have effects similar to PCBs, and may also be contributing to the problem. Because mink and otters are susceptible to the presence of persistent toxic substances, they are valuable biological indicators.

A second grouping of critical species that are useful in identifying problems related to persistent toxic contaminants are a variety of fish-eating birds susceptible to organochlorine compounds. Bald eagles, herring gulls, terns, herons and double-crested cormorants have all been used to document the effects of contaminants on bird reproduction. For example, during the 1950s and 1960s, the bald eagle population nesting on the shorelines was virtually eliminated from the Great Lakes because of exposure to DDT and dieldrin. In addition, dioxins and PCBs have resulted in associated reproductive impairment, including a high rate of congenital deformities. Many fish-eating bird populations integrate contaminants on an extensive scale, often reflecting the general contaminant levels from the adjoining lake system, not just the immediate locality near the Area of Concern.

Research should:

- Compile current distributional and historic records on critical species, using data from field naturalists and/or appropriate agencies. In addition, the quality of the existing habitat for these critical species should be assessed and inventoried. Where a suitable physical habitat exists, the re-establishment and subsequent successful reproduction of critical species may be used as indicators of successful remediation achieved through RAP implementation

- Establish the net uptake of selected contaminants in migrant species to assess the impact of visits to the Areas of Concern and

to investigate the contaminant burdens of resident littoral or riverine species to establish factors dependent on variability and age, and affecting contaminant concentrations. Agencies should arrange with trappers to collect and preserve mink and otter samples for chemical analyses. Similarly, the carcasses of bald eagles and osprey should be collected to determine levels of persistent toxic substances

- Determine the causes and establish the dose/response relationship in order to develop the cause/effect relationship between the decline in critical species and the levels of persistent toxic chemicals. Data on sensitivity due to chronic exposure (i.e. PCB, dioxins and furans) for specific birds and animals needs to be related or developed for species where information is unknown

1.4 Fish and Wildlife Habitat Classification

Habitat is a major factor affecting the community structure of fish and wildlife in aquatic and wetland ecosystems. Typically, the habitat within an Area of Concern has been reduced or eliminated since its natural pre-settlement condition. Since Areas of Concern often represent the present terminus of a series of habitats ranging from unchanged to completely modified, special classification and inventory techniques will be required for them. The Great Lakes Fishery Commission (GLFC), through its Habitat Advisory Board, is beginning to address this issue.

Research activities should:

- Develop and implement procedures for habitat classification which distinguish between adequate and inadequate habitat in significantly modified systems

1.5 Criteria to List/Delist Areas of Concern

Areas of Concern are defined as those locations (i.e. tributary mouths, harbors, embayments and connecting channels) where Great Lakes Water Quality Agreement objectives or jurisdictional standards, criteria or guidelines, established to protect uses, are exceeded and remedial measures are necessary to restore uses. There is a general frustration with this subjective and imprecise definition (i.e. use impairment) for Areas of Concern. Precise criteria (i.e. numerical standards) and a protocol for data interpretation to delist/list Areas of Concern from the Water Quality Board's list are needed. Criteria could be based on a suite of tests or protocols which would indicate the recovery of an area and the restoration of all beneficial uses. The information needed to develop defensible criteria will depend upon much of the research identified in this section. Such precise criteria and a protocol for data interpretation are essential in ensuring that Areas of Concern are restored to meet the objectives of the Great Lakes Water Quality Agreement.

Research should:

- Develop the necessary criteria which amalgamate conclusions from environmental research with socio-economic and political issues to enable the jurisdictions to assess the restoration of Areas of Concern

2.0 ECOSYSTEM DYNAMICS

Following the assessment of the physical, chemical and biological components within an Area of Concern, the interactions between these compartments need to be examined and understood in order to develop an effective remedial action plan.. These interactions include the combined effects of nutrients and contaminants on food web dynamics and contaminant body burdens as well as the impacts from the biological and physical movement of contaminants across the boundaries of the Areas of Concern. Modelling will be used to interpret these interactions. The responses to remedial measures by the various components must be both predictive and sufficiently accurate to allow for the most cost effective and socially acceptable remedial actions to be developed.

2.1 Relationships Between Contaminated Sediments and Biotic Health

The ultimate concerns regarding toxic contaminants in sediments are their biological fate and effects. Understanding the physical and chemical exchange processes, the uptake pathways and fates of contaminants, either as temporary or permanent residents in sediments, is required.

The partitioning of sediment contaminants between the soluble (pore water) and particulate phase is an important research area. Understanding this two phase partitioning and the interactions with the overlying environment is an essential step in examining the capture and release of contaminants in sediments. Contaminant movement associated with the particulate phase is mainly controlled by sediment resuspension, whereas movement in the soluble phase is mainly due to molecular diffusion. Fluxes in resuspended contaminated sediment can be estimated only if the amount of resuspended particulates can be measured. Likewise, diffusional fluxes of contaminants in pore water released from the sediments into the overlying water can be estimated only if concentrations within the pore water are known. This research will aid in understanding the pathways used by benthos in uptake or adsorption. It will also allow for relationships between concentrations in the particulate and soluble phase, and the body burdens of benthic invertebrates to be inferred.

Once important pathways are identified, the exchange rates must be determined to establish the relative significance of any particular route. Research should therefore be directed towards understanding these processes. Such understanding requires that measurements be made of the uptake and loss rates for specific contaminants. These measurements can be used in the uptake and fate models of contaminants.

Research should:

- Establish relationships between the concentrations of contaminants in pore water and whole sediment
- Characterize and quantify the diffusional flux of contaminants across the sediment/water interface, using state-of-the-art pore water gradient chemistry samplers and sediment resuspension samplers

- Determine the role of benthic organisms in mobilizing or modifying contaminants either through their own metabolism or through their effects on the biogeochemical environment (i.e. redox, organic matter, bacterial turn-over rates)

- Measure the effect of contaminant mobilization by fish (e.g. carp), which disturb and resuspend sediments

- Determine the role of microbial processes at the sediment/water interface in liberating nutrients and contaminants, either directly by excretion or indirectly by modifying the redox environment

- Determine and compare the rates at which contaminants are taken up by the resident biota and quantify further biomagnification. In the case of fish, uptake rates need to be compared for fish exposed to contaminated water and those exposed to contaminated benthic food organisms

- Identify the controlling factors which affect the body burden of contaminants in benthic organisms

- Determine the effects that contaminants have at the population and community level

Research needs are also proposed to develop appropriate protocols and criteria for testing sediment; testing would be conducted by evaluating in situ quality indicators, such as tumour incidence in resident fish and the community structure for fish and benthos. Results from these in situ assessments need to be linked with laboratory sediment tests.

Bioassays provide a direct means for assessing environmental toxicity. Even though recent IJC initiatives have proposed protocols for the assessment of toxic contamination, there are some concerns and limitations related to bioassays. Contaminants usually exert effects at the biochemical level, often by inhibiting enzymes or interrupting physiological processes. In the environment, however, effects are seen at the other end of the continuum of biological organization: changes in populations, communities and ecosystems. Finally, criteria for determining the significance of results in terms of environmental risk do not exist.

Research should:

- Develop appropriate criteria for bioassays so that both the need for and success of remedial action can be determined

- Compare results obtained from bioassay protocols implemented in a test site at an Area of Concern with those obtained from a clean control site. In addition, new bioassay tests need to be developed, using species indigenous to the Great Lakes and common in Areas of Concern

- Examine the relationships between selected bioassays and responses in field populations. While the effects on communities and ecosystems can best be studied by directly examining changes in

the environment, such methods can be used only after contamination has occurred. Any changes identified are difficult to ascribe to specific substances. Experiments can be done only by performing manipulations at the mesocosm level or by developing appropriate field bioassays with indigenous populations

2.2 Relationship Between Nutrient and Contaminant Levels in Biota

In Areas of Concern, as in other areas, the eutrophication and contaminants issues have been traditionally viewed separately. Contaminant activities have focused on identifying sources, environmental pathways and effects on biota, whereas eutrophication research and management strategies have focused on the relationship between nutrient inputs and biological productivity. Suspended material, which can alter the bioavailability of both nutrients and contaminants, has also been considered as a separate issue. Interactions between nutrients, contaminants and suspended material, if confirmed by further research, would have major implications for the management of both nutrients and contaminants, particularly where remedial measures are under consideration. Research to define predictive relationships between nutrients and contaminants is needed before management strategies linking the different issues can be developed.

Research should:

- Investigate the relationship between trophic status, community structure and the relative importance of the benthic and planktonic routes for the uptake of contaminants

- Investigate the relationship between nutrient availability and lipid content in aquatic organisms and the effects of that relationship on contaminant bioaccumulation and translocation

- Investigate the relative importance of dissolved organic matter as a source and the effect of dissolved organic matter on the bioavailability and degradation of contaminants

2.3 Effects of Nutrient and Contaminant Levels on Food Web Dynamics

Phosphorus management (i.e. bottom-up control) and fisheries management (i.e. top-down control) strategies have been implemented in the Great Lakes basin. Both strategies affect water quality (e.g. water clarity) and the structure of biological communities. Research is essential to elucidate the effects of top-down and bottom-up management, particularly in Areas of Concern, where the results of nutrients and fishery management are frequently first observed. Quantifying the impact of changes in food web dynamics on contaminant levels in fish is an important aspect of this issue.

Research should:

- Perform meso-scale experiments designed to quantify the impact of changing food web dynamics on the level of toxic substance in fish

- Identify the food which are responsible for the greatest transfer of contaminants to fish and wildlife

- Perform meso-scale experiments on simplified aquatic ecosystems, designed to measure the effects of alterations in nutrient supply and fish density on biomass and growth at all trophic levels

- Establish the community structure of zooplankton and benthos, especially with respect to animal size, which results in the optimum transfer of carbon to sport fish

- Field-verify hypotheses developed in the mesocosm experiments in the Areas of Concern

There may be beneficial effects on water quality in Areas of Concern as a result of fishery management. For example, the Science Advisory Board sponsored a food web workshop which examined food web effects on water quality. The proceedings show that an increase in predation pressure by piscivorous fish reduced planktivory, resulting in the proliferation of zooplankton and the reduction of algal densities. From the fisheries point of view, it is important that such effects be measured and fully understood in order that fisheries be treated as an integral rather than a peripheral component of the ecosystem.

Research should:

- Develop verifiable methods to measure the biomass and production of components at all trophic levels

- Measure the separate and combined effects that migratory and resident fish populations have on zooplankton, phytoplankton and macrophytes

- Examine and compare the feasibility of reducing chlorophyll a or other water quality indicators by piscivorous fish management with other nutrient and contaminant management initiatives

2.4 Exchange Between Areas of Concern, Nearshore Region and Open Waters

The nearshore region is heavily used for recreation and serves as a source of drinking water for numerous communities along the Great Lakes. The elevated concentrations of contaminants and nutrients which characterize an Area of Concern ultimately make their way to the open water, after interacting with the nearshore region. While the accumulation resulting from contaminants introduced into the Great Lakes has been measured in the sediments, water column and biological community of the open lake, little is known about the transition zone between the nearshore regions adjacent to the Areas of Concern and the open lake. The movement of pollutants from an Area of Concern into the open lake is a complex mixture of physical and biological transport mechanisms. It is necessary to determine the quality and quantity of contaminants transported by sediment and water movement as well as by biological transfer through passive movement (plankton) or fish migrations in order to understand the interactions between these zones.

Research should:

- Measure the physical transport of contaminants via suspended material and water from Areas of Concern into the nearshore and open lake regions

- Determine the role of the biological community in contaminant transport from the Area of Concern through the nearshore region into the open lake and vice versa

2.5 Synergistic and Antagonistic Effects of Pollutants

The simultaneous introduction of pollutants from point and nonpoint sources into Areas of Concern, with their limited water exchange and dilution, poses the possibility of toxicological interactions. Some combinations of toxic pollutants might multiply their detrimental effects, while others might actually reduce theirs. Ecotoxicological research, focused on the effects of both lethal and sub-lethal synergistic contaminants in certain mixtures under specific conditions, is required.

Research should:

- Develop toxicity screening procedures for sub-lethal concentrations of contaminant mixtures in controlled mesocosms

- Develop a contaminant mixture inventory in aquatic and sedimentary media

2.6 Human Risk Assessment

Contaminants associated with Areas of Concern could affect human health, primarily through the production and distribution of potable water, the consumption of contaminated fish and/or wildlife and through the recreational use of contaminated waters.

Research should:

- Develop a toxicological and risk assessment data base for contaminants identified in Areas of Concern, including consideration of the human health effects of exposure to contaminant mixtures

- Implement epidemiological studies to assess the impact of chemicals on resident human populations in Areas of Concern

- Investigate possible water treatment methods for the removal of contaminants from drinking water

- Investigate the risk posed by the consumption of contaminated fish and wildlife

2.7 Ecosystem Models

The biological fate and effects of toxic contaminants are of primary interest in Areas of Concern. Determining the role of various ecosystem compartments as sources and accumulators of contaminants is vital to making management decisions. However, as biological processes become incorporated into models, the complexity increases. An extreme example is the utilitarian ecosystem model, EXAMS, developed by the Athens EPA and modified for the Great Lakes as TOXIWASP. As these models become more complex, the information and skill required to run and interpret them increases considerably.

To develop an ecosystem model, specific information on concentrations and mass is required for biotic and abiotic compartments. It is necessary to take into account seasonal and climatic phenomena as well as information on the partitioning and cycling of contaminants. Once pathways have been identified, the exchange rates between the components need to be determined in order to establish the relative significance of a particular route. This process requires information on the rates of uptake and loss for specific contaminants.

Research should:

- Establish the complexity of the model that will adequately predict the fates and effects of contaminants identified in several representative Areas of Concern

3.0 SOURCES/TRANSPORT PATHWAYS

Identifying and measuring contaminants and nutrients should be a straightforward task; in practice it is not. Sources range in configuration and complexity, from diffuse (e.g. land runoff, atmospheric deposition, sediment release) to single continuous-flow effluent pipes. In many cases, identifying and measuring the constituents comprising the effluent may involve sophisticated and expensive analyses of complex sample matrices. Because of costs, the number of samples is limited and hence the accuracy and precision of the estimates is compromised. The research required to assist in this aspect of the remedial action planning process includes the development of statistical methodology, analytical methodology, and sampling strategies. The overall success of these protocols, when they are applied to Areas of Concern, can be best tested and verified with mass balance modelling, using data from representative Areas of Concern.

3.1 Point Sources

Contaminants generally enter receiving waters via point sources, making the task of measuring the constituents seem an easy task. Unfortunately, making statistically valid loading estimates is hampered by erratic flows and concentrations, analytical difficulties and a lack of sufficient funds to adequately sample. There are additional difficulties in attempting to identify contaminants in complex matrix effluents.

Research should:

- Develop monitoring schemes for point sources to produce loading data which will be statistically precise and accurate
- Develop and standardize methods for analyzing toxic organics at low concentrations in complex media (e.g. pulpmill effluents)
- Develop screening protocols for assessing the occurrence of new compounds or degradation products in samples collected as part of the routine monitoring scheme
- Develop a system for broad mass spectrum analysis after separation by GC, HPLC and other techniques to identify unknown or previously unrecognized compounds. The data from this finger-print would be archived for future evaluation
- Evaluate the microbiological (pathogenic and non-pathogenic) properties of effluents from the municipal, pulp and food industry sectors and assess their health risk
- Assess the toxicity of effluents on biota in the Great Lakes

3.2 Combined Sewer Overflows

Many of the urban centers in the Great Lakes basin have a portion of their wastewater collection system designated as "combined". This description indicates a link between the stormwater collection system and the sanitary sewer system which carries residential, commercial and industrial wastewater. During significant precipitation, such systems discharge an overflow mixture

of untreated storm runoff with sewage wastewater directly into the receiving waterbody, bypassing the treatment system. Regardless of their origin, these untreated discharges often contain microbiological pathogens, nutrients, organic compounds, metals and suspended particulates; thus, they need to be considered as potentially significant sources of pollutants. Where combined sewer overflows (CSOs) have been monitored, the results indicate that violations of water quality criteria and standards are frequent. In addition, data are generally insufficient to adequately quantify loads.

Research activities should:

- Develop a strategy to monitor the quality and quantity of CSO discharges
- Develop and validate urban runoff models to measure loads and assess their relative contribution
- Develop an appropriate suite of bioassays to determine acute and chronic toxicity linked with CSO discharges

3.3 Nonpoint Sources

Pollution attributed to nonpoint sources of contaminants are difficult to assess. Three general categories of nonpoint sources have been identified which can affect an Area of Concern. Most commonly addressed are nonpoint problems associated with agricultural practices (nutrients and pesticides). A second nonpoint source involves urban runoff, which includes direct runoff from streets and industrial waste, and sewage released into surface waters from combined sewer overflows. Urban runoff can be a mixture of numerous organic and inorganic constituents. The third category is comprised of waste dump sites or land fills which can leach contaminants into the receiving water or contaminate groundwater.

Nonpoint source research should:

- Establish a sampling strategy which will provide sufficient data to calculate loadings from the various nonpoint sources
- Develop a means of assessing the amount and degree of impairment to the region as a result of nonpoint sources

3.4 Sediments as Sources and Sinks

Sediments may either receive or release contaminants. Understanding sedimentary processes is crucial in Areas of Concern because, in most cases, sediments are highly contaminated. Sediment studies dealing with entrainment, resuspension and transport are relatively new research areas, where field measurements are extremely difficult and expensive. Information on resuspension and depositional rates needs to be obtained for predictive modelling and the optimal application of *in situ* sediment remediation procedures.

Research should:

- Identify and measure processes controlling resuspension and deposition in Areas of Concern, especially within the nearshore zone
- Establish the bioavailability of particulate-bound nutrients and contaminants
- Investigate the effect which suspended sediments have on sorption, photolysis, hydrolysis and other mechanisms which degrade contaminants
- Determine and differentiate the role of organic particles of aquatic and terrestrial derivation in contaminant transport and fate

3.5 Atmospheric Pathways and Inputs

There are two general topics to be examined with respect to the role of the atmosphere as a pathway for contamination. First, research needs to be conducted into the role of the atmosphere as a pathway for introducing suspended solids, nutrients and contaminants in Areas of Concern. Second, studies need to be conducted on the volatilization of contaminants, particularly mercury and volatile organic chemicals, released from the water body into the atmosphere.

Research should:

- Design sampling networks to identify and discriminate between local sources of contaminants in Areas of Concern versus those entering from regional transport
- Develop sampling equipment and procedures to link fluxes with specific atmospheric events (windstorms, inversions, frontal rain)
- Develop models to accommodate wet/dry/vapour transport processes
- Develop techniques to measure the effect of particle size on deposition and transfer rates across the air-water interface

Because the volatilization of organic chemicals from the waterbody may be a pathway for major loss, research needs to address this issue.

Research should:

- Develop and verify models to predict volatile releases, using in situ experiments and measurements
- Establish whether surface-active agents affect volatilization rates
- Determine the effects of organic matter and nutrient loading on water column and sediment processes, which convert contaminants (organic and inorganic) into volatile components

3.6 Mass Balance for Nutrients and Contaminants

Numerical models have proven useful tools in providing a planning framework within which research can be organized and priorities set. Models are also valuable as diagnostic tools to evaluate the results of research and monitoring within a holistic framework.

Environmental models vary in complexity. The first step in selecting or developing one for an Area of Concern is to clearly identify the questions to be addressed. The most straightforward and, in many ways the most valuable model for the remedial action planning process, is the mass balance model. It is employed to organize the introduction of contaminants into and the subsequent losses from the Area of Concern. Simply stated:

> Contaminant content change = Sum of all sources (external and internal) - Sum of all outputs - Sum of losses due to degradation reactions

The object of this exercise is to determine whether all the significant captures and releases of contaminants have been identified and measured. This information is critical for detailed modelling efforts: evaluating the design of monitoring programs and assigning priorities to remedial actions. Mass balance models are most often used to examine a system at time scales of several months or longer.

Research should:

- Test and verify the model's sensitivity to uncertainty, in particular to highly variable contaminant loading rates
- Evaluate the use of fugacity modelling to aid in determining fates and pathways

4.0 SOURCE CONTROL

The objective of the U.S.-Canada Great Lakes Water Quality Agreement is the virtual elimination of persistent toxic substances from the Great Lakes Ecosystem. The release of persistent toxic substances into the waters of the Great Lakes basin from a variety of sources has resulted in the accumulation of these chemicals in biota and, has lead to toxicological effects. Thus, the top priority of Remedial Action Plans is to eliminate sources of persistent toxic substances and then to clean up the contaminated environments. Persistent toxic substances are released from point sources such as chemical manufacturing sites, processing plants and municipal sewage treatment plants as well as nonpoint sources such as chemical landfill sites and agricultural drainage. In most AOCs, the point sources of persistent toxic substances are already known and their elimination can be hastened by the development of effective and economical alterations to industrial processes or to pollution treatment facilities. Non-point sources of persistent toxic substances, on the other hand, may not be as well quantified and the scale of control strategy, research and development is difficult to select without better information.

Lastly, once the programs are in place to control the existing sources of persistent toxic substances there is a need to anticipate the kinds of problems that may be posed in the future by chemicals new to commerce that may enter the Great Lakes ecosystem.

4.1 Point Sources

There are many points in the industrial effluent and domestic sewage treatment facilities where the effective control of persistent toxic chemicals awaits the results of present and future research and development effort. Both types of facility are characterized by significantly different problems. For example, municipal sewage treatment plants are at risk because they may be the unwitting recipients of unlawful releases of persistent toxic substances. Though these plants may remove a proportion of the substances from the sewage, through microbiological degradation or by physico-chemical processes, the effluent may still contain unacceptable concentrations of the substances. Removal of the substances into sludge causes logistical problems of safe sludge disposal. Thus there is a need for municipalities to collect information about the sources of persistent toxic substances to their sewage treatment plants. This information must include detailed knowledge of the sewer system, industries that discharge to the system and an analysis of the chemicals in the various branches. The type of control technology developed and implemented depends on an evaluation of each system's users.

In industrial plants, however, the inputs are fairly well known and chemical waste streams are often at high concentration. The control of contaminants at these locations is the most efficient control strategy because concentrations are high and opportunities for recycling exist. Research can develop and evaluate new methods for eliminating contaminants in these types of effluents. Perhaps, more importantly, research and development can identify new manufacturing processes which do not produce the same quantity of contaminants.

Research should:

- Develop and evaluate new methods for treating high strength wastes (e.g. those from anaerobic and physical-chemical processes)
- Identify processes, using halogens, which are liable to produce halogenated organic compounds, and develop other reaction conditions to eliminate the production of those compounds
- Develop methods for trapping and destroying volatile organic compounds which escape into both municipal sewage and industrial treatment and collection systems
- Continue to develop effluent guidelines for the discharge of toxic organics, using such techniques as QSAR and biological screening protocols to improve the rate of progress in establishing guidelines for new chemicals
- Develop techniques to immobilize or destroy toxic components in sludges from treatment plants (e.g. solidification, chemical treatment and thermal treatment - both oxidizing and non-oxidizing)
- Identify materials obtained from waste streams or emissions which can be recycled to useful products either through purification or in combination with other materials
- Conduct mass balance studies for contaminants in industrial and municipal effluent systems to determine the net input of contaminants to the Areas of Concern (i.e. cooling water from Areas of Concern may already be significantly contaminated)

4.2 Nonpoint Sources

The manufacture and use of persistent toxic substances in the Great Lakes basin has left a legacy of chemical wastes in landfill sites. Release of these substances from surface runoff of leachate or from groundwater movement continues to pose dangers to fish and wildlife and to human health. There is a priority need to describe actual and potential sources of persistent toxic substances in chemical landfill sites and to identify the parameters within which control possibilities can be researched.

The other major activities which result in non-point discharges are agriculture and transportation. Present agricultural practices lead to releases of licensed and restricted (e.g. DDT and aldrin) biocides to tributaries of AOC's. While research is on-going to control these losses to aquatic systems, the approach is one of minimizing economic losses to the farmer. The optimal economic application techniques may not be sufficient to protect all uses of the aquatic resource

Research on controlling inputs of chemicals (e.g. hydrocarbons, asbestos, rubber breakdown products, lead and other internal combustion products) from transport vehicles is fairly intense but it needs to extend into options for controlling these substances once they are deposited in the aquatic system.

Research should:

- Aid in the development of remedial techniques to decontaminate aquifers types common to AOC's.
- Aid in the development of stream side buffer strip criteria for minimizing losses of biocides from farm land.
- Identify locations in the transportation system where contaminants can be trapped and treated.

4.3 The Proactive Approach

One of the major themes of the 1987 Science Advisory Board Report was to promote a proactive, anticipatory approach toward preventing harm to the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem. To help implement this approach, research is needed to prevent the formation of new hazardous wastes and to estimate the hazards associated with those which already exist. Research should also focus on control at or near sources through reuse, recycling, recovery and waste exchange. Finding substitutes for halocarbon compounds used in industry and agriculture would go a long way to diminishing the annual load of the most persistent group of chemicals to Areas of Concern. Finally, the implementation of an effective accidental spill response and preventive action plan throughout the manufacture, transport, use and disposal cycle of persistent chemicals requires innovation in both technical and economic areas.

5.0 IN SITU REMEDIATION

In some Areas of Concern, the control of external sources of contaminants and/or nutrients will not be adequate to attain the quality of water, sediment or biota that is desired. In these cases, the internal sources or mechanisms, together with biomagnification, combine to maintain high contaminant levels. The in situ remediation options can be categorized as Biological Alteration, Contaminated Sediment Management, and Water Column Chemistry and Physics Control.

5.1 Water Column Manipulation - Physical and Chemical

5.1.1 Aeration

Concentrations of dissolved oxygen can be extremely low in the bottom water of some Areas of Concern. Low oxygen concentrations greatly limit the extent to which fish and invertebrates utilize the waterbody and have a strong influence on the biogeochemistry of metal ions and nutrients. Under conditions of no dissolved oxygen, metals and nutrients are released from the sediments into the water column, resulting in serious water quality problems. However, the effect of low oxygen concentrations on organic contaminant degradation or release from the sediments has not been fully examined.

The injection of air into reservoirs, lakes and rivers has been successfully implemented in many regions to aid in improving fish habitat and water quality degradation related to eutrophication. The effects of air injection on contaminant related processes need to be studied.

Research should:

- Evaluate the effect of oxygen concentration at the sediment/water interface on the transport, degradation or immobilization of organic and inorganic (metals) contaminants
- Determine the influence that oxygen concentrations have on in situ dehalogenation reaction rates in sediments and water columns
- Measure oxygen consumption, biological production rates and physical oxygenation processes to provide proper scaling for an air injection pilot project

5.1.2 Destratification

The tendency for water bodies over five or six meters deep to thermally stratify has many ecosystem consequences, particularly in systems where nutrient and organic loadings lead to anoxic conditions in the bottom waters. The effects include a decrease in fish habitat and the trapping of contaminated sediments. The residence time of contaminants in a stratified Area of Concern is also likely to be increased.

Destratification techniques, which alleviate problems associated with anoxia, frequently include the addition of air. This technique could also be used to prevent the accumulation of contaminated sediments in biologically sensitive depositional zones.

Research should:

- Investigate the feasibility of using destratification techniques to prevent the accumulation of contaminated sediments in valued habitat areas

5.2 Contaminated Sediment Management

Contaminated sediments link the Areas of Concern, an occurrence that is highlighted in the revised Great Lakes Water Quality Agreement as amended by the Protocol signed on November 18, 1987. Annex 14, which specifically deals with contaminated sediments, states that the Parties are committed to: "develop a standard approach and agreed procedure for the management of contaminated sediments" and "evaluate (with biennial updates) existing technologies for the management of contaminated sediments such as isolation, capping, in-place decontamination and removal of polluted bottom sediment."

It is essential that a demonstration program with some specific projects be designed and implemented in a manner that will produce scientifically defensible results. The potential for the demonstration program to be applied beyond the Areas of Concern, and indeed beyond the Great Lakes, will be greatly enhanced if the program is specifically designed with a central research component.

5.2.1 Dredging

From 1975 through 1979 approximately 4.6 million m^3 of sediment were dredged annually in the Great Lakes', much of this activity occurred in Areas of Concern. Most of this material (50%) was placed in confined disposal facilities (CDFs), while a lesser amount (38%) was deposited in open water; the remaining 4% was disposed of elsewhere. In general, CDFs are located along the shoreline near the dredge site or within the drainage basin of an Area of Concern.

There are several concerns which exist as a result of dredging and sediment disposal activities. These include biological effects at various trophic levels in the immediate vicinities of the dredging operation, the physical impairment of nearshore habitat and the reintroduction of hazardous chemicals to the water column. Furthermore, the leaching of chemicals back into the aquatic ecosystem once the material has been contained in a CDF is also a concern.

Therefore, it is imperative that further research be conducted to develop criteria which will reflect the biological impacts associated with the disposal of dredge spoils. In addition, further research needs to be conducted on disposal mechanisms other than the present CDFs or open water dumping.

Research should:

- Develop techniques to evaluate the ecosystem contamination resulting from dredging activities, focussing on the transport and fate of contaminated suspended sediment liberated by the

operations, and on the sediment/water interactions in the newly exposed sediment of dredged areas

- Develop new design criteria for CDFs to ensure that contaminants remain isolated from the open waters

- Develop techniques to evaluate the impacts of contaminants on wildlife, which congregate during the early phases of CDF infilling

5.2.2 Inactivation via Chemical Treatment or Capping

Dredging for any purpose is expensive, even if the disposal does not require a confined disposal facility. Areas of contaminated sediment are frequently large and generally more extensive than the areas dredged for navigation. There is a need for techniques that are more economical and less disruptive than dredging to immobilize or inactivate contaminated sediment. Lime treatment is one such technique currently under development; other treatments are being developed.

Research should:

- Develop and test treatment techniques designed to reduce the recycling of heavy metals, nutrients and organic contaminants at the sediment/water interface

- Investigate the feasibility of capping or covering contaminated sediments as well as that of injecting the sediment into deep wells. The choice would be based on the characteristics of the Areas of Concern

5.2.3 Microbiological Rehabilitation Techniques

Manipulation of bacterial processes may provide a new approach to the restoration of the Areas of Concern. For instance, the inhibition of some bacterial processes could lead to a substantial reduction of internal nutrient and contaminant recycling and bioavailability, while selective stimulation of others could result in increased regeneration particularly from the sediments.

Recent experiments on the large-scale innoculation of selected bacteria indicate that such applications may be feasible in Areas of Concern. The objective is to achieve the maximum biodegradation of contaminants at the sediment-water interface. Laboratory and small scale pilot research programs in this area need to be carried out in order to assess the potential benefits provided by the natural degradation of residual sediment-bound contaminants.

Research should:

- Evaluate the feasibility of using selected bacteria for their ability to degrade toxic organic chemicals and to rehabilitate contaminated sediments

5.3 Biological

5.3.1 Fish and Wildlife Habitat Rehabilitation

Because they are located in river mouths and embayments, many, if not most, of the Areas of Concern have a great influence on the productivity and biological functioning of the adjacent Great Lakes. These regions typically consist of large, productive, shallow areas with substantial habitat diversity and originally were important habitats for fish and wildlife production. Successful remediation of the Areas of Concerns could result not only in reducing contamination in the immediate region but also reduce contamination in the adjacent lake system. Consequently, this would result in economic benefits through reductions in contaminant levels in fish and wildlife on a regional as opposed to just a local level.

Research should:

- Establish the relative importance of fish and wildlife production in Areas of Concern as opposed to the open lake or unaltered wetland habitats

- Investigate the potential for the enhancement of artificial habitats for the various life stages of valued fish and wildlife species endemic to the various natural environments in the Areas of Concern

6.0 SOCIO-ECONOMIC CONSIDERATIONS

6.1 GLWQA Context

Although the GLWQA inherently focusses on water quality, its essential purpose is to "restore and maintain the integrity of the waters of the Great Lakes ecosystem, and therefore to eliminate or reduce to the maximum extent practicable the generation and discharge of pollutants caused by human activity." Important social and economic considerations are apparent throughout the Agreement, and underlie in particular, Articles II, III and VI, which deal with the impact of human activities.

The terms of reference provided for the joint institutions in the GLWQA empower the Water Quality Board, at the direction of the Commission, to "examine the appropriateness of (agreement related) programs in the light of present and future socio-economic imperatives." The Science Advisory Board, in developing guidelines for the review of Remedial Action Plans, has stated that the plans "must consider the demographic, economic and institutional context within which remedial decisions are made, the financial and institutional resources that must be mobilized if remedial action is to occur, and the primary economic and institutional impediments to short-term remediation and sustained long-term protection."

As a general principle, Article 2(a) provides that RAPs "shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in Areas of Concern." The ecosystem approach incorporates social and economic concerns as important subsystems and integral components of the ecosystem.

Article 4(a) defines those elements to be included in the plan, and refers to (iii) "an evaluation of remedial measures in place", (iv) "an evaluation of alternative additional measures to restore beneficial uses" and (vii) "a process for evaluating remedial measure implementation and effectiveness."

Impairment of use, referred to in Annex 2 of the Agreement under Article 1(c), includes examples related to social impacts, such as (ix) "restrictions on drinking water", (x) "beach closings", (xi) "degradation of aesthetics;" and examples of economic impacts, such as (vii) "restrictions on dredging activities", and (xii) "added costs to agriculture or industry." Other examples can be construed as impairing both social and economic benefits, for example (xiv) "loss of fish and wildlife habitat."

In summary, these articles comprise the mandate concerning applied socio-economic research under the GLWQA for the joint institutions. Unlike other planning and impact assessment processes which involve negotiation, the RAP process has an agreed goal, an international imperative for clean water. In this context, therefore, socio-economic impacts may be assessed in terms of current social and economic conditions, and from the options, forecasts may be suggested for remediation. Research on the social and economic implications of these options addresses the need for a plan that is: a) acceptable; b) sustainable; c) feasible; and d) eventually can be implemented.

6.2 Regional Perspective

It is clear that a Remedial Action Plan must address a range of human activities and underlying factors, including those related to the air and land, in order to understand and resolve problems of water quality. Since the restoration of beneficial uses to an Area of Concern is the major criterion by which the plans will be judged, remedial planning must recognize past, present and future uses, as well as the impact of change.

Beneficial uses must be sustainable under the GLWQA. This concept implies the integration of uses. Further, it involves an identification of the various combinations of competing and complementary uses, and significant agreement among those upholding the preferred views. The preferred combination of uses enables RAP teams to proceed with examining the nature and causes of impaired uses and describing the actions required for remediation.

The social and economic values associated with the existing uses of an area need to be measured and refined. This action is the starting point for viewing the potential of an area not constrained by current uses, and recognizes its inherent finite nature.

Uses may include:

- municipal water supply
- industrial and commercial water supply
- recreational boating activities
- commercial navigation
- recreational fishing
- commercial fishing
- swimming and other body-water contact sports
- winter sports
- visual and other aesthetics
- wildlife related activities
- waste disposal
- residential and nearshore commercial activities
- natural state activities

Sufficient time for the implementation of a remedial action and the restoration of uses is critical and should be explicit in the RAP. Sustainable development in an Area of Concern requires time allotments so that macro-economic and broader societal trends can be related to an economy supported by the environment.

Goals for the use of the ecosystem also need to be related to goals for regional economic development; often this linkage is implicit or not readily apparent. Integration of the RAPs with regional official plans for development should be a consequence of planning with municipal and other stakeholders. The question of environment/economy integration and sustainable development within the context of the regional economy is part of comprehensive planning and must be resolved with a view to all remedial actions.

6.3 Benefits Assessment

The benefits of remediation in an Area of Concern can be viewed as:

- economic or resource
- economic impact and income generating benefits
- other social

Economic benefits are those that increase net societal welfare, viz increased recreational opportunities, enhanced real property values, expanded tourism, and local exports of goods and services. These benefits may be quantitative (increased production of goods or more fishing days) and/or qualitative (increased value of land or better fishing experiences). They may also be directly related to uses, such as an increase in swimming activity, or intrinsically valued, such as residents feeling better about the place where they live, or investors and the business sector being optimistic about the future of investments and businesses in the area.

Intrinsic values are those that involve no monetary or financial transaction but which have an economic value all the same. These intrinsic values have been identified more specifically as "options value" (retaining natural ecosystems for potential future use), "bequest value" (preservation of ecosystems for future generations) and "existence value" (satisfaction from the knowledge that the ecosystem is inherently safe, clean and productive even if one may never use it). These values have traditionally been estimated through the use of contingent value surveys (questions of willingness to pay and/or accept compensation) of residents of an area to produce measures which can then be related to other economic benefits and costs.

Economic impacts can be expected to result from capital investment. These gross cash or financial flows may result in additional jobs and personal income for the local economy, for both the short and the longer run, and need to be identified for each remedial plan and related to an allotment of time. So called "multiplier effects" may lead to further or second generation impacts in regional economies, particularly those economies with excess productive capacity. These impacts have traditionally been identified through the use of regional input-output models.

Other societal benefits might include the improved distribution of income or *in lieu* income, such as greater access for lower income residents to recreation facilities in an improved Area of Concern. Human health improvements from both physiological (diseases related to occupational or domestic air/water/land pollution sources) and psychological (stress and depression) perspectives may also be relevant.

6.4 Costs of Remedial Actions

The costs of remedial actions can be assessed only after they have been selected and potential changes have been identified. Costs, like benefits, can be grouped as:

- economic or resource,
- economic impacts and financial flows
- other social

More attention needs to be focussed on the costs to determine and address their impact and distribution. Opportunities and mechanisms for funding the costs of remedial actions, although a separate exercise from socio-economic analysis per se, should be considered. Some examples are listed at the end of this section.

Economic costs are associated with a wide range of planning actions:

- enhanced municipal and industrial waste treatment
- elimination of atmospheric, aquatic and land based emissions
- removal and clean up of in-place contaminants from water, air and land based activities
- mitigative measures (e.g. habitat improvements) to encourage other types of economic benefits from the Area
- restoration and enhancement activities designed to permit new sustainable developments
- costs to social programs resulting from displaced economic and cultural activities, or changed economic activities

6.5 Methodology for Analysis

The use of various forecasting methodologies to develop options is a technique which holds promise as an analytical tool from which different planning possibilities and outcomes can be assessed. Each option, with its economic and social benefits and impacts, should be presented with an assessment of its economic and social costs. The restoration of beneficial uses, particularly those competing for the finite resource base, should be identified in each option so that questions on goals can be readily assessed. This approach also provides a medium for subsequent discussions of appropriate funding mechanisms, sources of funding, and for the sharing of the responsibility for remedial action.

6.6 Summary and Research Framework

Socio-economic research develops a perspective that is important in terms of public attitudes and perceptions. In order to implement policy and direct change it is important to understand not only how people perceive a problem, but why they perceive it in that way. Understanding attitudes and perceptions ultimately leads to an understanding of behaviour and provides a scientific basis for projecting from the past and present into the future. The following summary is suggested as a basic framework for applied socio-economic research in RAPs:

6.6.1 Water Use

- Document historic and existing use, demands and management goals affecting the water in the Area of Concern
- Project future requirements

6.6.2 Plan Acceptance

- Determine the most appropriate means for public consultation, the level of involvement sought, and the role for public participation as a part of the planning process (e.g. How will conflicts be reconciled, and what is the decision-making process?)
- Develop a means for soliciting the views of that portion of the public which does not participate initially
- Provide a basis for understanding the public's knowledge and awareness of major issues, and the implications of that understanding for policy actions and plan implementation

6.6.3 Plan Feasibility

- Identify options that are achievable, desirable and affordable
- Determine social and economic impacts in terms of abatement costs for the private sector, remedial costs for the public sector, employment effects, and costs to individuals
- Determine the requirements for sustaining environmentally appropriate behaviour
- Determine appropriate time and personnel requirements to implement the plan
- Define nongovernmental roles and responsibilities for implementation of the plan, and the policy framework required to address them

6.6.4 Opportunities

- Assess social and economic opportunities and benefits occurring as a result of proposed actions (e.g. enhanced employment in the municipal and service sector for the pollution control industry, tourism [internal and external benefits], investment in urban areas and redevelopment of waterfront lands, industrial potential for established locations unencumbered by environmental liabilities, recreation and nonparticipatory benefits.)
- Assess economic policy linkages to ensure sustainable ecosystems

6.6.5 Research Examples Specific to Economics

- Environment/economic competitiveness:

  -Impacts of environmental quality on a local level in the Great Lakes on economic competitiveness and economic development

  -Impacts of various remediation and regulatory approaches on competitiveness

(A case study of the past relationships between levels of degradation and controls as opposed to levels and kinds of economic development in a community would be most useful as a starter.)

- Potential for economic development in tourism and other economic sectors:

  -At the community level, both with and without present local environmental degradation in the Great Lakes

  -At the state/province or regional level, both with and without local and widespread environmental degradation

- Specific economic sectors responsible for degrading areas of concern and the reasons for the degradation:

  -Case studies of past failures and successes

- Better estimation of the various economic benefits and costs of remediation, degradation and protection

- Regulatory options and other control strategies for protecting the water quality of the Great Lakes:

  -Relative economic efficiency and effectiveness, and other economic and social implications of various options and strategies

- Better estimation of the regional economic impacts of remediation and other environmental changes, and of regulations

- Public finance:

  -Methods of financing remedial action

- Natural resources accounting:

  -Tracking the natural resources and environmental impacts of public and private actions in the region

6.6.6 Some Socio-economic Instruments Relevant to Plan Implementation and Research

Influence of Tax and Fiscal Measures

- Emission Charges
- Tax Incentives
- Tax Credits
- Bonding Systems
- Liability Insurance
- Input Pricing
- Marketable Pollution Rights

Information and Technology Opportunities

- Demonstration Programs
- Case Study Profiles
- Technology Awareness Programs
- Targeted Information Packages
- Environmental Audit Programs
- On-site Training
- Formal Training
- Environmental Accounting Training

Industrial Support and Involvement

- Waste Exchanges and Brokers
- Environmental Audit, Consulting, and Service Industry Development
- Register/Data base of Environmental Support Services
- Directory/Data base of Waste Treatment and Clean Process Technologies
- Environmental Technology Warranty Program
- Centres of Technical and Marketing Excellence

Stakeholder Participation

- Industry Task Forces
- Regional Round Tables
- Environmental Mediation
- Environmental Reporting
- Industry Advisory Councils

Review and Evaluation of Regulatory Measures

- Environmental Targets
- Annual Environmental Return
- Environmental Defense Fund
- Withdrawal and Discharge Permits
- Government Program Procurement and Support Code
- Compliance Evaluation

Advocacy

- Clean Industry Awards
- Assertion of International and National Leadership
- Stakeholder Support

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