REHABILITATING GREAT LAKES ECOSYSTEMS

Great Lakes Fishery Commission

TECHNICAL REPORT No. 37

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop coordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

REHABILITATING GREAT LAKES ECOSYSTEMS

edited by

GEORGE R. FRANCIS
Faculty of Environmental Studies
University of Waterloo
Waterloo, Ontario N2L 3G1

JOHN J. MAGNUSON
Laboratory of Limnology
University of Wisconsin-Madison
Madison, Wisconsin 53706

HENRY A. REGIER
Institute for Environmental Studies
University of Toronto
Toronto. Ontario M5S 1A4

and

DANIEL R. TALHELM
Department of Fish and Wildlife
Michigan State University
East Lansing, Michigan 48824

TECHNICAL REPORT NO. 37

Great Lakes Fishery Commission
1451 Green Road
Ann Arbor, Michigan 48105

December 1979

CONTENTS

REHABILITATING GREAT LAKES ECOSYSTEMS

edited by

George R. Francis, John J. Magnuson, Henry A. Regier
and Daniel R. Talhelm

EXECUTIVE SUMMARY

In June 1977, the Great Lakes Fishery Commission (GLFC) requested its Scientific Advisory Committee to review the state of the art for ecological rehabilitation of aquatic ecosystems, and assess the feasibility of applying it to the Great Lakes. This study is the response to that request.

The study group reviewed the relevant literature and held consultations through various means with over fifty people in the United States and Canada, each recognized to be knowledgeable on some aspect of the overall subject. No original data were gathered nor pilot studies conducted, so that the conclusions presented here are the considered best judgement of the study team.

The main conclusion is that comprehensive ecosystem rehabilitation strategies for the Great Lakes are in general feasible to develop. They should be initiated first for smaller ecosystems such as bays and harbors, and tailored to the particular conditions and stresses impacting on particular areas. Once this is done, we can assess whether to adopt additional basin-wide rehabilitative measures to include those being carried out for fisheries by the GLFC and for water quality improvements by the International Joint Commission (IJC).

A comprehensive ecosystem rehabilitation strategy must address measures to alleviate the key stresses affecting the aquatic ecosystem. It should also specify rehabilitation objectives in terms of a consistent set of ecological indices and the conditions needed to sustain them. This will point to other environmental and resource management measures needed to complement the stress removal measures.

Rehabilitation prospects are addressed at three ecosystemic levels: the whole Great Lakes basin; individual lakes; and major, critical ecosystems within the lakes. Operationally, the primary attention of managers will likely focus on the third level since each ecosystem at that level is subject to a different mix of stresses.

Some sixteen kinds of man-induced stresses were identified and examined at a generic level. Each was reviewed to point out some major ecological manifestations, some useful rehabilitative techniques, and a measure of current feasibility from technical, economic and institutional viewpoints. The following human stresses were analyzed: fishing and other harvesting of biota; introductions and invasions of exotic species; microcontaminants, toxic wastes and biocides; nutrients and eutrophication; organic inputs and oxygen demand; sediment loading and turbidity; stream modification; dredging and resource extraction; infilling, shoreline structures and island creation; water level controls; weather modification; water diversions; entrainment and impingement; thermal loading; ice control; major catastrophes; acid rain; and draining of wetlands.

Cost-benefit considerations will help in the selection of particular rehabilitative strategies. A wide array of interests, organizations and groups can and will contribute in implementing the strategies. Some guideline considerations relating to these issues are given in the report.

The general approach to ecosystem rehabilitation proposed in this report was tried out through consultations on Green Bay and the Bay of Quinte as case examples. There was a general consensus that the approach is helpful for directing attention to key topics in need of further information and analyses. Therefore this approach could serve as a useful framework to help orient efforts towards developing effective strategies for smaller ecosystems.

We recommend (1) disseminating the report in oral, technical and popularized forms for appropriate audiences; (2) using the report as a working document for developing the Strategic Great Lakes Fishery Management Plan, sponsored by the GLFC, and for coordinating activities of the various commissions, (GLFC, IJC, and the Great Lakes Basin Commission (GLBC)); (3) initiating action planning for ecosystems through local workshops and through a formal reference to the IJC; and (4) supporting research on ecosystem rehabilitation by developing the action-planning process, by coordinating and exploring research on rehabilitation issues through workshops and working groups, and by reviewing GLFC activities on rehabilitation.

PREFACE AND ACKNOWLEDGEMENTS

The task of our study group has been to assess whether it is now feasible to rehabilitate and restore Great Lakes ecosystems.

Early in our study we decided to incorporate the concept of partial restoration into our concept of rehabilitation. We recognized that full restoration to primitive conditions was out of the question. Thus the term "restoration," which we once used in discussing these ideas, became redundant and we have now simplified the wording of our objective accordingly.

The GLFC funded our two-year "feasibility study." The funding was very modest by the usual standards of international studies, such as the references to the IJC; in fact, something less than one percent of the cost of some recent references. Most of the work on which this report is based was volunteered by collaborators or by the institutions and agencies that employ the collaborators. Perforce our modus operandi was not intended to include new research but rather focused on an interactive, consultative process by which some fifty knowledgeable experts directly considered aspects of rehabilitation feasibility. Hundreds more were involved less closely in the context of scientific symposia, conferences, seminars and commission meetings in which we presented and discussed aspects of feasibility.

The appended chronology notes some of the more significant events in our two-year process. The list of names includes those who contributed substantively to the contents of our report.

Ken Loftus may be recognized as a primary stimulus for this study. On the Canadian side especially he has led in fisheries policy reform which incorporates major elements of rehabilitation of fish stocks and of their habitats and ecosystems. In these and other respects, such as his role in IJC activities, Murray Johnson has been a co-leader. On the U.S. side Howard Tanner and Wayne Tody of Michigan have exerted strong leadership in fisheries policy reform along somewhat similar lines.

Carlos Fetterolf and Bill Maxon helped when we needed it, and Carlos reviewed the whole document in detail.

Dale Ronayne and Dee Lovely performed the arduous typing chores, always with good humor.

A chronology of the main meetings held in connection with the ecosystem rehabilitation study follows:

Canada-United States Seminar on Management Issues for the Great Lakes, University of Western Ontario, November 1976 and University of Michigan, April 1977 chaired by George Francis and Leonard Dworsky. Ecosystem rehabilitation goal for the Great Lakes discussed at the seminars and at a session of the May 1977 meetings of the International Association for Great Lakes Research (IAGLR) at Ann Arbor.

GLFC Annual Meeting, Sault Ste. Marie, Ontario, June 1977. Proposal submitted urging Commission to promote an ecosystem rehabilitation goal for the lakes on the occasion of revisions being made to the 1972 Canada-U.S. Great Lakes Water Quality Agreement and to take initiative to work with IJC towards this end. GLFC requested its Scientific Advisory Committee (SAC) to review state of the art and feasibility of applying it to the Great Lakes.

Study Steering Committee chaired by John Magnuson and Henry Regier established by SAC, June 1977. Committee met repeatedly. Preparation of review papers for the study commissioned by December 1977.

Workshop session among authors of review papers, on the occasion of the 21st Annual Meeting of IAGLR followed by a symposium presenting these papers to IAGLR, Windsor, Ontario, May 1978.

GLFC Annual Meeting, Rochester, New York, June 1978. Draft set of papers and progress report tabled.

Workshop on ecosystem rehabilitation techniques, Toronto, Ontario, January 1979. Revision and elaboration of material for Chapter 3 of report.

Workshop on socio-economic aspects of ecosystem rehabilitation, East Lansing, Michigan, February 1979. Revision of material for Chapter 4 of report.

Workshop on ecosystem rehabilitation for Green Bay, Green Bay, Wisconsin, April 1979. Material for Chapter 6 of report.

Workshop on ecosystem rehabilitation for the Bay of Quinte, Belleville, Ontario, May 1979. Material for Chapter 6 of report.

Report of the study reviewed and revised at the Trout Lake Biological Station, Wisconsin, May 1979.

GLFC Annual Meeting, Toronto, Ontario, June 1979. Final draft of report presented.

Study collaborators also presented related papers at the January 1978 meetings of Canadian Environmental Professionals in Toronto, Ontario; August 1978 meetings of the Ecological Society of America in Atlanta, Georgia; and March 1979 meetings of the North American Wildlife Conference in Toronto, Ontario. In addition university seminars were conducted on the subject at Ann Arbor, Waterloo, Madison, Toronto and Thunder Bay.

The contributors of text (denoted by asterisks) and participants in workshops were as follows:

David Armstrong,* Water Chemistry Department, University of Wisconsin-Madison, Madison, Wisconsin.

Alfred Beeton, Great Lakes and Marine Waters Center, University of Michigan, Ann Arbor, Michigan.

Ralph Bergman, Bay-Lake Regional Planning Commission, Green Bay, Wisconsin.

Richard Bishop,* Center for Resource Policy Studies and Programs, University of Wisconsin-Madison, Madison, Wisconsin.

Stephen Born,* Department of Urban and Regional Planning, University of Wisconsin-Madison, Madison, Wisconsin.

Keith Bridget-, Lake Ontario Fish Stock Assessment Unit, Ontario Ministry of Natural Resources, Richmond Hill, Ontario.

Jonathan Bulkley,* Department of Civil Engineering, University of Michigan, Ann Arbor, Michigan.

Noel Burns,* Canada Centre for Inland Waters, Canada Department of the Environment, Burlington, Ontario.

John Cairns,* Center for Environmental Studies, Virginia Polytechnic Institute, Blacksburg, Virginia.

John Carr, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Ann Arbor, Michigan.

Steven Chapra,* Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, Michigan.

W. Jack Christie,* Glenora Fisheries Research Station, Ontario Ministry of Natural Resources, Picton, Ontario.

John Cooley, Great Lakes Biological Laboratory, Canada Department of Fisheries and Oceans, Burlington, Ontario.

Carol Cutshall, Bay-Lake Regional Planning Commission, Green Bay, Wisconsin.

Betsy David, Wisconsin Department of Natural Resources, Madison, Wisconsin.

Jack Day, University of Wisconsin-Green Bay, Green Bay, Wisconsin.

Jack Donnan,* Ontario Ministry of the Environment, Toronto, Ontario.

George Francis,* Faculty of Environmental Studies, University of Waterloo, Waterloo, Ontario.

Vicki Garsow, University of Wisconsin Sea Grant College Program, Green Bay, Wisconsin.

Charlie Goldman,* University of California, Davis, California.

A. P. (Lino) Grima, Institute for Environmental Studies, University of Toronto, Toronto, Ontario.

Harold Harvey,* Department of Zoology, University of Toronto, Toronto, Ontario.

H. J. (Bud) Harris,* University of Wisconsin Sea Grant College Program, Green Bay, Wisconsin.

Eddie Herdendorf, F. T. Stone Laboratories, Ohio State University, Columbus, Ohio.

Ross Horrall,* Marine Studies Center, University of Wisconsin-Madison, Madison, Wisconsin.

Don Hurley, Glenora Fisheries Research Station, Ontario Ministry of Natural Resources, Picton, Ontario.

Eugene Jaworski,* Department of Geography and Geology, Eastern Michigan University, Ypsilanti, Michigan.

Murray Johnson, Great Lakes Biolimnology Laboratory, Canada department of Fisheries and Oceans, Burlington, Ontario.

Philip Keillor, University of Wisconsin Sea Grant College Program, Madison, Wisconsin.

Lee Kernen, Wisconsin Department of Natural Resources, Green Bay, Wisconsin.

Dianne Kolenosky, Lake Ontario Fish Stock Assessment Unit, Ontario Ministry of Natural Resources, Richmond Hill, Ontario.

Gerry LeTendre, New York State Department of Environmental Conservation, Cape Vincent, New York.

George Mackin, Retired business executive and advisor to University of Wisconsin Sea Grant College Program, Green Bay, Wisconsin.

John Magnuson,* Laboratory of Limnology, University of Wisconsin-Madison, Madison, Wisconsin.

Don McNaught,* State University of New York at Albany, Albany, New York.

C. Ken Minns, Great Lakes Biolimnology Laboratory, Canada Department of Fisheries and Oceans, Burlington, Ontario.

James Moore, Wisconsin Department of Natural Resources, Green Bay, Wisconsin.

Ken Nicholls, Ontario Ministry of the Environment, Islington, Ontario.

Ray Oglesby,* Department of Natural Resources, Cornell University, Ithaca, New York.

Dan Olson, Wisconsin Department of Natural Resources, Green Bay, Wisconsin.

Glen Owen, Ontario Ministry of the Environment, Kingston, Ontario.

Mercer Patriarche,* Institute for Fisheries Research, Michigan Department of Natural Resources, Ann Arbor, Michigan.

Robert Ragotzkie,* University of Wisconsin Sea Grant College Program, Madison, Wisconsin.

Henry Regier,* Institute for Environmental Studies, University of Toronto, Toronto, Ontario.

Glen Robinson, Ontario Ministry of the Environment, Islington, Ontario.

David Rosenberger,* Great Lakes Regional Office, International Joint Commission, Windsor, Ontario.

Paul Sager, University of Wisconsin-Green Bay, Green Bay, Wisconsin.

William Sonzogni,* Great Lakes Basin Commission, Ann Arbor, Michigan.

George Spangler, Department of Entomology, Wildlife and Fisheries, University of Minnesota, St. Paul, Minnesota.

Daniel Talhelm,* Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan.

Dan Tilton,* Great Lakes and Marine Waters Center, University of Michigan, Ann Arbor, Michigan.

David Weininger,* Environmental Research Laboratory, United States Environmental Protection Agency, Duluth, Minnesota.

James Weirsma, University of Wisconsin-Green Bay, Green Bay, Wisconsin.

Tom Whillans,* Institute for Environmental Studies, University of Toronto, Toronto, Ontario.

1: BACKGROUND AND OVERVIEW OF STUDY

Expressions of concern over deteriorating Great Lakes water quality and biota are not new. Fisheries have declined and deteriorated since early European settlement of the Great Lakes basin and various forms of rehabilitation have repeatedly been recommended by international groups of fisheries experts since about 1870 (Regier and Applegate 1972). When the International Joint Commission (IJC) was first established in 1912 under the Boundary Waters Treaty of 1909 one of its first tasks was to investigate and confirm the extent of pollution in the lakes.

Especially during the past 20 years or so, public concern has widened and magnified in response to continued Great Lakes degradation. This concern is slowly mobilizing and organizing, as reflected when a binational citizens group, Great Lakes Tomorrow, emerged in 1975. This group advocates creating rehabilitation policy goals for the lakes, opening governmental decision-making processes dealing with the lakes to more public inspection and participation, and challenging decisions made in one jurisdiction which create transboundary problems for other jurisdictions around the lakes (cf. Grima and Wilson-Hodges 1977, Grima 1978).

Governments have responded to the continued degradation of the Great Lakes by more extensively studying and initiating ad hoc remedial measures. Both the studies and the measures are becoming increasingly firm and permanent institutions. All federal, state and provincial jurisdictions around the lakes have established and have gradually strengthened pollution control programs and fishery management programs.

Both nations cooperate on Great Lakes problems on a permanent, but still quite tenuous footing. Under the 1955 Convention on Great Lakes Fisheries, the binational Great Lakes Fishery Commission (GLFC) recommends measures to permit the maximum sustained productivity of fish stocks of common concern, coordinates fish stock assessment, research and management, and formulates and implements sea lamprey control. The IJC has been continuously and increasingly involved with Great Lakes issues since 1964 when it received a reference to investigate (for the third time) the extent of pollution in the lower lakes, and another reference to search for engineering solutions to lake level fluctuations. For the past 15 years, IJC has continuously worked on pollution problems under the 1972 and 1978 Great Lakes Water Quality Agreements which followed its 1970 report on the 1964 reference. It is also searching for engineering solutions to control lake levels, monitoring air pollution at three transboundary locations around the lower lakes, and, under a new 1977 reference, studying Great Lakes diversions and consumptive water uses.

The 1972 Great Lakes Water Quality Agreement strongly committed the United States and Canada to reduce pollution entering the lakes by undertaking concerted programs and measures. This resolve was reaffirmed in the 1978 Agreement, "The purpose of the Parties is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Gunnerson and Oakley (1974) described the overall approach to carrying out the terms of these Agreements. Progress and results are described both in annual reports to the IJC (IJC/Great Lakes Water Quality Board 1974 through 1978) and in the final sets of reports from the two references incorporated into the 1972 Agreement (IJC/Upper Lakes Reference Group 1976; IJC/International Reference Group on Great Lakes Pollution from Land Use Activities, PLUARG, 1978).

Other initiatives during the 1970's substantially improved our understanding of the Great Lakes ecosystems and the impacts of human uses on them. GLFC published a series of case histories of the fisheries in the lakes (GLFC 1973) and sponsored in part major scientific symposia on two of the most important fish communities represented in the lakes (SCOL: Loftus and Regier 1972; PERCIS: Colby 1977). Under the aegis of the International Hydrologic Decade, Canada and the United States jointly researched Lake Ontario limnology during the International Field Year on the Great Lakes (Ludwigson 1974). The Great Lakes Basin Commission compiled a 27 volume set of background information to serve as a framework for planning water, shoreline and associated land resources in the U.S. portion of the basin (GLBC 1975-6). It also compiled data from the basin for the 1975 U.S. National Water Assessment (U.S. Water Resources Council 1977), and more recently adopted program priorities to deal with water conservation measures, toxic substances control, and impact assessments of total allowable pollution loadings on whole lakes (GLBC 1978).

Concurrently, related research institutions around the Great Lakes have expanded and become stronger. These include the Canada Centre for Inland Waters, the U.S. Great Lakes Fishery Laboratory, the U.S. Great Lakes Environmental Research Laboratory, and various university centers particularly those in the United States that receive federal Sea Grant funds. The eight states and one province involved have expanded their respective planning and management-oriented research activities. Many consulting groups have been formed. The International Association for Great Lakes Research (IAGLR) serves as an important forum for exchanging scientific information within the research community through annual meetings. Its Journal of Great Lakes Research was launched 1975 as a successor to the proceedings of annual Great Lakes conferences. Some 2000 scientific papers have been presented at these meetings from 1959 through 1975 (Phillips and Veinot 1977).

Yet, unmistakably, the conditions over much of the Great Lakes ecosystem continue to deteriorate. Intensified research and surveys pertaining to the lakes over the past decade, while still ad hoc and fragmented, have succeeded in documenting much better the extent of this deterioration and some of its causes and consequences. This research directly and implicitly indicates that more "holistic" systems perspectives will help in devising effective strategies for reversing this deterioration and in guiding priorities for research and data gathering. The prevailing "reductionist" approaches to research and practical problem solving are necessary but not sufficient for reversing the continued degradation of the lakes ecosystem (Francis and Regier 1977, Regier 1979).

The 1972 Water Quality Agreement called for a fifth-year review. As the review approached, two quite independent series of steps were initiated, both serving to urge the Parties to the Agreement to recast their efforts in an ecosystem perspective. One arose from internal discussions within the IJC's Great Lakes Research Advisory Board. As a result the Board recommended that the IJC adopt an "ecosystem quality" perspective to guide its responsibilities under the Agreement (IJC/Research Advisory Board 1977, 1978). The IJC has endorsed as policy the need for an ecosystem approach (IJC 1978) and the basic ideas are being articulated further (Vallentyne 1979).

The other set of steps arose from the reconvened Canada-United States University Seminar in 1976-77. This group, drawn mainly from academics and civil servants employed by agencies having direct responsibilities for the lakes, first met in 197 1-72 to discuss policy, planning and management issues pertaining to the Great Lakes. At that time the Seminar recommended extending the scope of binational cooperation by strengthening the role of the IJC (Dworsky, Francis and Swezey 1974). The 1971-72 seminar group anticipated that reviewing the 1972 Agreement would involve some public discussion and consultation with interested groups in both countries, and that negotiators of the new 1978 Agreement would be open to suggestions from such groups. While it subsequently became clear this was not to be so, the seminar group made several suggestions. Some have subsequently been taken up by the Expert Committee on Societal Aspects of Great Lakes Water Quality of the IJC's Science Advisory Board (formerly called the Research Advisory Board).

One suggestion was to reconsider the goals being sought for the lakes. The prevailing approach of the 1972 Agreement (which will be continued under the 1978 Agreement) defines Great Lakes restoration goals in terms of an ever-lengthening list of specific water quality objectives agreed to on an individual parameter by parameter basis. In contrast, the 1976-77 Seminar concluded that goals for Great Lakes environmental management could be more usefully interpreted in terms of ecological rehabilitation and restoration. The reason is that various mixes of pollutants, each present in "acceptable" amounts may synergistically affect water quality. Another reason is that water quality defined in this way will not necessarily protect valuable biota from undue stress or contamination even though the objectives agreed to tried to allow for this. Thriving communities of ecologically sensitive fish and other aquatic vertebrate species would better indicate the extent to which the Great Lakes were or could ever be "restored'‘-the stated goal of the 1972 and 1978 Agreements.

To follow up this line of reasoning, a proposal was drawn up and discussed informally among a number of people, and then presented to GLFC (Francis and Regier 1977). It urged Canada and the United States to make a "strong, irreversible and concerted commitment" towards the ecological rehabilitation and restoration of the Great Lakes, and to submit a reference to the IJC to define such an implementation program, particularly for the most degraded areas. The new (1978) Agreement provided the opportunity to mobilize resources and expertise in both countries to address this question. The proposal also suggested that GLFC offer to serve as a "lead agency" within the appropriate group or board established under such a reference.

GLFC endorsed the idea in principle, then requested its own Scientific Advisory Committee (SAC) to review the state of the art and feasibility of applying it to the Great Lakes. This report is a result of that directive. In late 1977 IJC and GLFC met and agreed to work more closely together. Both Commissions have accepted the desirability of working within a broad "ecosystems" approach. The stage is set for thinking through appropriate strategies.

Approach to the study

In consultation with GLFC/SAC the investigators agreed that the review should result in a "policy-oriented" report, written in a style which would make it accessible to the well-informed layman, politician, and resource manager. As the manuscript now stands each of the four editors can understand the whole,-a minor achievement in itself. The science and scholarship involved are, we hope, respectable. However, given the aim of the report and the scope of the material, we could not provide all the evidence, argument and documentation to convince the most skeptical or reluctant expert.

The whole question of the state of the art and the feasibility of applying it to selected areas of the Great Lakes was to be determined as a matter of some collective best judgment solicited from the "scientific community." There was no provision for additional data gathering or pilot projects usually associated with the idea of a "feasibility" study. Some of the latter cost over a hundred times more than the present study.

A small Steering Committee directed the work over the two year period 1977-1979. It recognized that at least three sets of issues had to be addressed. The first set concerns the science and the applied science for managing aquatic ecosystems: Is there sufficient knowledge and experience to determine whether strategies for ecosystem rehabilitation are technically feasible in the Great Lakes? The second set of issues relates to the social and economic feasibility of such strategies: If it is technically possible to rehabilitate ecosystems, what economic and social considerations have to be taken into account? Finally, assuming that strategies can be carried out and are worth doing: What institutional changes, if any, would have to be made to facilitate their successful implementation?

The Steering Committee addressed these issues in several different ways. The main one was to invite knowledgeable and experienced persons to discuss and prepare review papers on selected aspects of the issues. In Windsor in May 1978 the first set of drafts was discussed by the authors at a one-day workshop, then orally presented at a one-day symposium during IAGLR's 21st annual meeting. The draft papers themselves were tabled at the 1978 annual meeting of the GLFC in Rochester and circulated for comment.

In Toronto in 1979, the contributing authors and a few other persons with particular expertise convened a workshop to review and assess the natural science and engineering aspects of ecological rehabilitation of aquatic ecosystems. This was followed by two workshops, at Green Bay and the Bay of Quinte, at which our general conclusions were examined in the light of these two specific situations.

In this process scientists and others from numerous disciplines developed a reasonable consensus. While the Steering Committee in no way wishes to leave the impression of unanimity on all the conclusions reported here, it does have reason to believe that they do represent the considered best judgement of some 50 recognized experts.

The report is organized to reflect the three sets of issues addressed by the study. Chapters 2 and 3 review the reconstituted history of the human impacts on the lakes as these have affected fish communities; they summarize and discuss the salient features of the lakes viewed as natural systems as they are now understood scientifically; they review the results from attempts to rehabilitate small inland lakes elsewhere, and they describe relevant work towards rehabilitating the Great Lakes. The main conclusion of this state of the art review is "yes" to the question of whether it is technically feasible to develop and apply ecosystem rehabilitation strategies to the Great Lakes. Chapter 3 reviews the various approaches which could be used to elaborate such strategies.

Chapter 4 discusses the social and economic feasibility of embarking on these strategies, from a broad economic perspective. There are two interrelated questions. One is how to reliably estimate monetary values of fish and other aspects of aquatic ecosystems. Values that could be found are summarized. The second is how to decide how much and which investments are economically justified to maintain or upgrade the aquatic ecosystem as the resource base which yields these returns. This in turn raises an important practical question of how to develop a kind of "ecological production function." What kinds of ecological effects could be reasonably expected from investing in different possible strategies? How do these ecological effects influence societal values? The conclusion is that while investments in maintaining this resource are generally justified, given the orders of magnitude of the benefits involved, specific values must be estimated on a case by case basis, where rehabilitation objectives have been specified and the means for reaching them spelled out.

Chapter 5 raises the issue of whether the present structure of institutional arrangements on both sides of the lakes facilitates or frustrates rehabilitation. "Institutional arrangements" here refer to the division and coordination of various functions and activities among a vast array of governmental and other organizations, each having its own diverse purposes, responsibilities, and expertise. The standing structure of institutional arrangements for water, shoreline and associated land resource planning and management in the Great Lakes basin is indeed impressively complex. It constitutes a kind of "organizational ecology" of its own, which is also in need of analysis and understanding if new goals and tasks are to be given to it.

While the organizational effectiveness of these existing arrangements cannot be thoroughly assessed in this report, Chapter 5 reviews the existing "basic policy framework" through which resource planning and management is conducted for the Great Lakes. It then outlines the approach which could be considered for identifying the main "actors" in an ecosystem rehabilitation policy field. This "inter-organizational system" should then be reviewed principally by the "actors" themselves, with a view to working towards some consensus on the goals to be sought and the strategies to be pursued. The actors must create open, cooperative, consultative arrangements to effectively implement the strategies.

This general approach is examined in the context of the two case examples, Green Bay and the Bay of Quinte; see Chapter 6. Persons directly involved in research or otherwise knowledgeable about these bays found that they could successfully adapt the overall approach outlined in this study to develop ecosystem rehabilitation requirements in these two situations.

Overall, then, the report is optimistic. Without underrating the difficulties and the knowledge gaps, it concludes that there is enough information and understanding to embark on the strategies discussed. They are "do-able," they are worth doing, and for the most part the authority, interests and expertise exist to undertake them. Chapter 7 contains recommendations for developing action programs.

Some basic terminology

The term "ecosystem" refers to an essentially natural complex of interlinking entities and processes which operate within some part of physical space. Physical space is simply a context which can be bounded by reference to geographic, hydrologic and atmospheric factors. Boundaries around a particular ecosystem usually cannot be specified precisely, but this is not crucial. In the case of the Great Lakes for example, the whole drainage basin of all the lakes can be viewed as an ecosystem for some purposes. For other purposes, it might be more appropriate to choose a "sub-system" such as one of the lakes, or a bay such as the Inner Bay at Long Point on Lake Erie, or a small lagoon on the point itself. The real focus of interest in ecosystems is on the self-organizing, dynamic processes of the system rather than on its boundaries.

A parallel can be seen with reference to human settlements. Cities are the focus of interest for the interlinkages of human activities and institutions within the "built environment." Yet there is also a hierarchic sequence which can be used for different purposes. Cities are components of a formally organized larger metropolis, and both may be perceived within some partially organized megalopolis. The Great Lakes megalopolis is a complex interlinked urban network which extends across and beyond the whole of the lower Great Lakes basin, and in the view of ekisticians it has important systemic properties of its own (Leman and Leman 1976).

The structure and functions of ecosystems may be viewed on different scales or levels, depending on the problems or interests being addressed. All too often, the wrong scale of perception restricts awareness, perception and understanding of ecosystem properties. This also occurs when institutional boundaries are accepted as limits. Humans use ecosystems through mixes of property rights and of numerous organizations each with set administrative and jurisdictional limits. These latter boundaries are important in practice largely because they shape the institutional arrangements through which ecosystems are used and abused. Such boundaries have no reality in the ecosystems themselves except as they happen to fall on ecosystemic discontinuities, a rare event.

This reminder is warranted for the Great Lakes, because various jurisdictional boundaries, especially the international one, have in fact limited the extent to which larger ecosystem properties have been perceived or acted upon. Ecosystem rehabilitation strategies will not be effective if jurisdictional boundaries are not transcended.

It may be helpful at the outset to draw some working distinctions between the term "rehabilitation" and other terms which are sometimes used to express similar notions. The main distinctions among various terms may be sketched with the help of Figure 1.1, here modified from an earlier version (Magnuson et al. 1979).

Consider an ecosystem in which man's influence is as yet minimal and negligible. Should it be *preserved* in that wild state? If so, some policy barriers against its use and abuse will need to be erected and maintained. If no barriers are erected, or if any such barriers are broached, then the system will respond to whatever human influences impact it.

The arrow-head end of the curved path in the figure specifies the current state of a typical Great Lakes ecosystem. At least eight policy options can be identified according to the various smaller arrows shown.

If no effective consideration is directed toward the ecological functioning of an ecosystem, and new uses are added ad libitum, then the ecosystem will very likely *degrade,* or degrade further into an ecological slum. The dominant power groups in society may seek to counter political objections to further degradation by undertaking *palliative* measures. A common political response of a palliative nature, used mostly to buy time during which degradative uses are allowed to continue, is to fund research or studies of a type that have no close relevance to the ecological processes involved. The net impact of such palliation is generally further degradation.

Alternatively, degradative uses may be permitted to continue with the proviso that some *mitigative* measures are undertaken that would reduce the extent of the more deleterious aspects of the degradation.

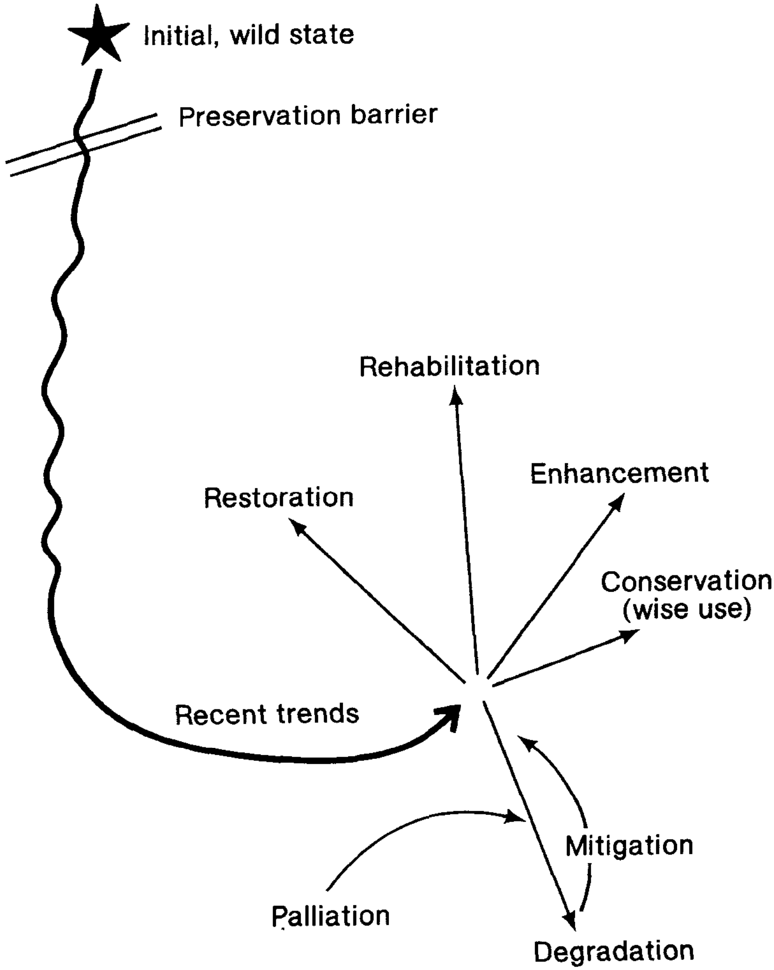

Figure 1.1. Sketch to illustrate meanings of some notions commonly used in discussions of policies concerning renewable resources and the natural environment (Regier 1979).

Cynics may dismiss most mitigative efforts as the sugar coating on a bitter pill.

The term *conservation* has often been defined as “wise use” or “multipurpose use” or “the greatest good for the greatest number for the longest possible time.” This usually involves an interminable succession of piecemeal additions of new more intensive uses through time and a stepwise ecological shift away from the initial wild state.

Enhancement in an extreme form is *culture* in which the ecosystem is brought under close human control,-as close as necessary to effect the relevant human purposes. Less intense enhancement may involve combatting some feature of an ecosystem that is widely held to be undesirable, such as the production of mosquitoes in wild swamps or black flies in unpolluted streams. Desirable exotic species, such as various salmon and trout, are often added to waters as enhancement measures.

Rehabilitation is generally used pragmatically in the sense that it may involve several of the measures already identified above except perhaps palliation and further degradation. In addition it will likely include *restorative* attempts to recover some of the features of the initial wild state currently perceived as particularly desirable. Thoroughgoing *restoration* would involve a shift all the way back to the initial state, which is generally impossible.

Rehabilitation images

Great Lakes ecosystems cannot be thoroughly restored because some of the past ecological changes are irreversible, and many of the present and future industrial, commercial and other uses of these ecosystems will continue to affect the ecosystems. On the other hand, thorough degradation is clearly unacceptable to the vast majority of the residents of the Great Lakes basin.

Rehabilitation is therefore a midway course, a compromise. The main goal of rehabilitation is to stop and reverse the overall long-run trend toward ecological degradation. The lakes can only be rehabilitated in a pragmatic way since we have no tested theory of ecological rehabilitation, nor for that matter of the economic and institutional aspects. How far a rehabilitative initiative might proceed will presumably always remain an open question politically.

Some relatively undegraded parts of the Great Lakes ecosystem can still accommodate numerous valuable, sensitive uses that have been diminished elsewhere. The following listing offers an image of what a fully rehabilitated or restored ecosystem would be like, in that we could do all of them.

> Drink water without fear of ingesting harmful viruses, bacteria, protozoa and poisons.
>
> Eat fish and waterfowl knowing that they are relatively uncontaminated by dangerous chemicals.
>
> Swim without becoming infected by disease or soiled by waste films on the water surface.
>
> Enjoy the beauty of pebble beaches that are uncontaminated by abnormal algal growths.
>
> Relax in the sand without becoming soiled by industrial and domestic wastes.
>
> Delight in clear waters in seasons when the waters normally should be clear.

Canoe or sail without encountering surface scums of wastes and offensive "floatables."

Study with pleasure a healthy ecological mosaic in the coastal zone.

Watch birds, plants, mammals and fish in their natural settings doing what they have always done.

Angle with the firm expectation of encountering large numbers of preferred species of fish.

Hunt waterfowl and wildlife produced or accommodated in the coastal zone.

Harvest commercially valuable species of fish and furbearers in profitable quantities.

Maintain dwellings near shore with confidence that nearby natural amenities will not diminish in value.

Administer profitable parks, playgrounds, marinas and resorts that will enjoy high popularity indefinitely.

Feel secure in the knowledge that not everything natural is expendable for some group's immediate interests.

Take pride in the mere existence of undegraded ecosystems not far from our teeming cities.

It must be stressed that natural ecosystems are not entirely idyllic from the viewpoint of urban humanity. Far from it. Nature has many unpleasant and dangerous features such as violent storms, days of excessive heat or of bitter cold, patches of poisonous plants, waters infested with leeches and organisms that cause swimmer's itch, standing waters that breed mosquitoes, clear streams that produce swarms of black flies, occasional windrows of dead fish that died of natural causes, and so on.

It will be a long time before some of the most degraded ecosystems of the Great Lakes can be rehabilitated so as to accomodate even half of the sensitive uses listed above. Presumably they will never recover to the point that all can be accommodated-at least not within the present era of industrial-urban civilization. But to realize some sensitive uses is much better than to realize none at all. For this we need to continue in our attempts to rehabilitate even the most degraded parts of the Great Lakes.

2. LAKE ECOLOGY, HISTORICAL USES AND CONSEQUENCES

A balanced, comprehensive rehabilitation strategy should incorporate some restoration elements, particularly with the more degraded ecosystems and with especially desirable features that have since been suppressed. Restoration implies some shift toward earlier conditions. The nature of those early conditions and how they were interrelated within an integral, functioning ecology can be "backcasted" from a wide variety of kinds of information. Then we wish to understand the causal mechanisms that have produced the current ecological conditions in order to inactivate the degradative causal mechanisms or to redirect them toward rehabilitative goals, or introduce new mechanisms. Many partial rehabilitative attempts have already been made-how successful have they been? What more is needed?

Early information sources

Our image of the initial state is imperfect. Even in fields such as cartography where our information was relatively good 200 years ago, it is clear from an examination of old maps that we cannot precisely characterize the Great Lakes from past records. Often our earliest record must serve as the benchmark. These can be supplemented by data from "retrospective monitoring" using paleoecological, paleolimnological and anthropological approaches.

The earliest literate observers were the French Jesuits who reported widely on the natural history from about 1630 until around 1791 (Thwaites 1959: Levere and Jarrell 1974). Writings of Sulpician and Recollet orders and various French regime explorers offer complementary naturalist-type information (Orford 1968). Subsequent ecological observations are passed on through the Hudson's Bay/Northwest Company records, especially the 1705 to 1940 Post Journals (Moodie 1977). Few of these documents have been fully studied in the context of our current interests concerning the Great Lakes.

One of Linnaeus' disciples, Pehr Kalm, came to the lower St. Lawrence Valley in 1749; he and his botanist predecessors were chiefly interested in useful herbs for transplantation to Europe (Levere and Jarrell 1974). Aquatic organisms generally were not among the first of the species of a region to be addressed by competent taxonomists. Offshore waters posed particularly difficult logistic challenges, thus a reasonably complete description of fish species in these lakes was not achieved until about 1850 (Dymond 1964a). Macro-invertebrates were not comprehensively described until about the 1930s, though some survey reports date back to 1871 (Robertson and Blakeslee 1948, Henson 1966). Some groups of plankton, fungi and bacteria still are not well described except in a few areas of the lakes (Davis 1966).

Cartography flourished in the 17th and 18th centuries but the first relatively complete shoreline survey of the Great Lakes was not achieved until the 1820s (Bayfield 1816-1824). Bathymetric information reached a useful state of completeness with U.S. Lake Survey charts after 1852 (Blust 1976). Areas potentially suitable for harbors were surveyed and resurveyed periodically in some hydrographic and ecological detail beginning in the 1780s (Whillans 1977).

Geology was the pre-eminent science of the mid-19th century. Geological surveys of the various states and of Canada produced voluminous reports including some that addressed ecology and limnology of the Great Lakes. For example, the Ohio Geological Survey published extensive papers on fish by David Starr Jordan.

Systematic climatological surveys were begun here and there during the period of early geological surveys. More comprehensive interpretations date from the late 1800s (Stupart 1896).

What might now be termed "ecological studies" began in the Great Lakes towards the end of the 19th century with J. E. Reighard, B. A. Bensley, and H. B. Ward as pioneers. On the Canadian side fairly complete summaries of fishery landings date from about 1865. Some fishery officials such as J. W. Kerr and S. Wilmot left much useful, well-interpreted information for the period beginning about 1860. On the American side fairly comprehensive fisheries surveys were undertaken in connection with the decennial censuses, beginning with the 1870s. When fish hatching and stocking of exotics became the primary policy of fishery agencies in the 1880s, the various fish commissions began to produce large annual reports which also dealt, inter alia, with pollution incidents and fishery regulations.

McAndrews, Berti and Norris (1973) describe the tools and techniques of "retrospective monitoring." Paleolimnological studies like that of Stevenson and Benninghoff (1969) and paleoecology as demonstrated by Warwick (1978) emphasize the potential of these approaches. Over 100 species of large aquatic organisms have been identified from archaeological digs, with the majority of this work having been done in the 1970s (Whillans 1978 MS).

A more nearly complete data set now exists on the nature and extent of human stresses on these aquatic ecosystems than on their original state. The inadvertent deleterious consequences of development did not go unnoticed and numerous surveys, studies and accounts of legal proceedings may be found in the literature and in archives since about 1820. Sources are many, varied, and generally well cross-referenced.

Original conditions

Mean annual air temperatures since 1840 in the Great Lakes region have exhibited cycles with an amplitude of about 2 C and an overall increase of about 1.5 C (Thomas 1968).

The range of water levels in the different lakes during the past century has been from 1.2 to 2.0 m (Richards 1969) owing largely to variations in rainfall. Water levels have also gradually changed as a result of isostatic rebound of the earth's crust following glaciation. Rates in meters per century have ranged from 0 on Lake Erie to 0.5 on the north shore of Lake Superior (Peach 1969). Effects on biota were likely limited to local shifts in distribution. At the time Europeans first settled the

Toronto region, what is now Toronto Harbour was protected by a long sandspit (Fig. 2.1). In 18524 and 1858 this spit was severely breached by storms with a resultant modification of the benthic ecology of the Harbour.

In early times, wetlands, tributaries, marshes and bays: served wide-ranging organisms for one or two periods each year; were the habitat of valued sedentary species; acted as partial traps for transient nutrients; and stabilized some insecure shorelines. Streams prior to the stresses of agricultural and industrial society were cooler, carried less silt, and had more even flow throughout the year. They were undammed, unchoked by pollutants and had an array of riffle and pool habitats.

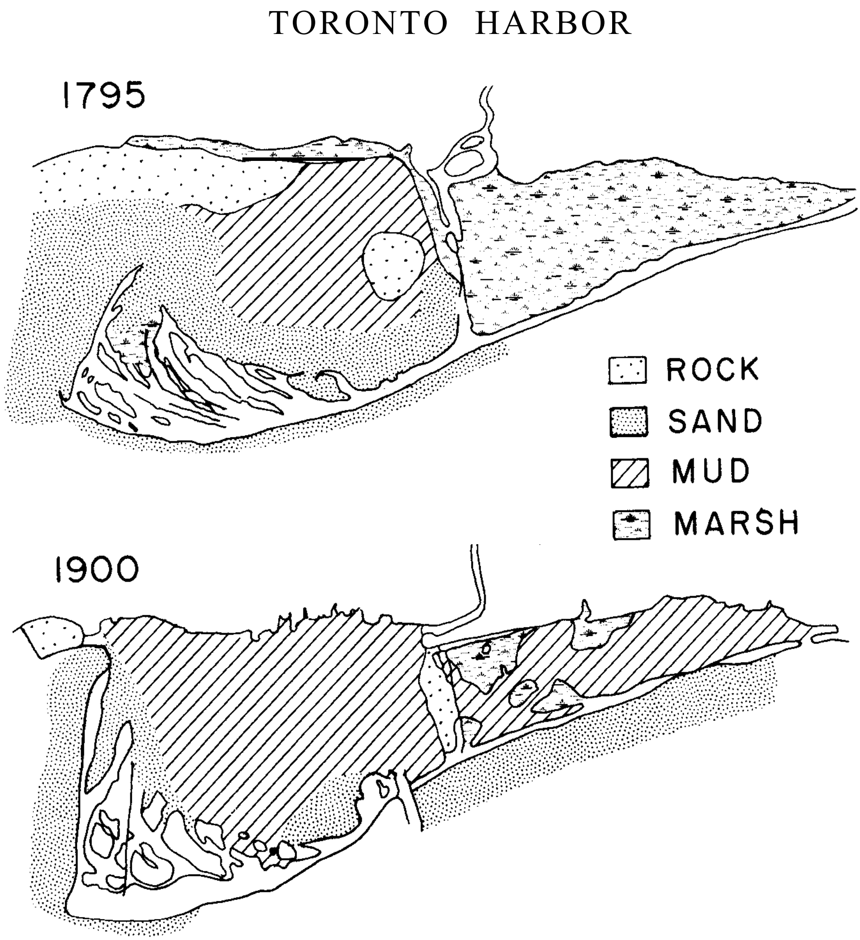

Figure 2.1. Modification to Toronto Harbor with time (from Whillans 1977).

We might speculate that the higher temperature of the water from the streams after land settlement may have caused a small average increase in nearshore temperatures of the lakes in summer. Direct loading of heat from electric generating plants has greatly expanded in recent decades. Almost all of this discharge has been to the nearshore zone.

Beeton (1976) summarized characteristics of water quality in offshore environments which are probably similar to those in early historic waters with mean depth greater than 15 m:

-total dissolved solids less than 100 mg/l;
-Secchi disc depth greater than 6 m;
-chlorophyll less than 4 μg/1;
-total phosphorous less than 16 μg P/l;
-dissolved oxygen distribution orthograde or if clinograde, greater than 60% oxygen saturation in deep water;
-annual primary productivity less than 100 gC/m^2/yr.

The logitudinal ionic profiles of Beeton and Edmondson (1972) as extended by the GLBC/Fish Work Group (1975) (Figure 2.2) illustrate how ionic concentrations have changed from early times.

Fisheries scientists have sought to discover how individual fish species, as well as "communities" of fish species, have responded to various natural and man-made stresses. Three symposia stand out: 1971, SCOL, Salmonid Communities in Oligotrophic Lakes (Loftus and Regier 1972), 1976, PERCIS, Percid International Symposium (Colby 1977), and the 1978 Symposium on Selected Coolwater Fishes of North America (Kendall 1978). These will soon be augmented by the 1979 Sea Lamprey International Symposium (SLIS) and the 1980 Stock Concept Symposium (STOCS), both sponsored by GLFC.

We judge that the fish associations of about 1800 were dominated by large individuals of large species. The species involved were sturgeon, lake trout, lake whitefish, northern pike, muskellunge, walleye, channel cattish and, in Lake Ontario, Atlantic salmon. We venture a guess that perhaps 50% of the total biomass of all fish in these lakes was contributed by individuals over 5 kg in weight. In 1977 the comparable proportion is infinitesimally small. The large fish species perhaps played roles not unlike the roles of the large trees in a mature forest. Compared to other organisms of the lake ecosystems, many fish were relatively massive and old, in some cases reaching ages over 50 years. Thus, they must have had a "conservative" function analogous to that of trees on land.

Our judgements about the conditions of the Great Lakes 200 years ago are summarized in Table 2.1. Basically the lakes provided cool and cold water habitats of low fertility. Primary productivity was low, oxygen was present in deep waters year around. Even in midsummer, stream flow was abundant with cool, clear water. Wetlands, marshes, macrophytes, bays, and rivers provided a rich mosaic of shallow water habitats. Large sized organisms dominated many taxa. There were numerous locally adapted stocks of salmonines and coregonines. There were no Pacific

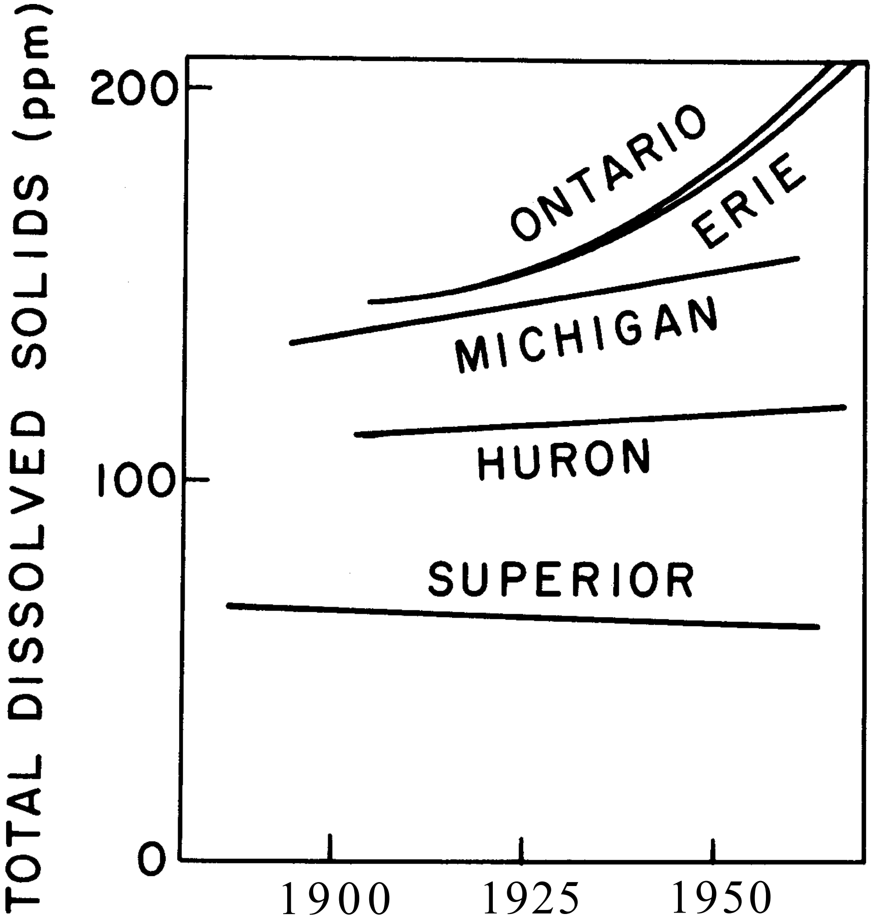

Figure 2.2. Changes in measured levels of total dissolved solids in the water of the Great Lakes. Modified from Fig. 8-5 in GLBC/Fish Work Group (1975).

salmon, brown trout, rainbow trout, rainbow smelt, alewife, carp, goldfish, white perch or the zooplankter *Eurytemora affinis,* and sea lamprey were confined to Lake Ontario. Some unique species or subspecies now absent were present, i.e., several coregonines and blue pike, and from portions of the basin, The Michigan grayling.

Human-induced changes in Great Lakes ecosystems

The degree of degradation of Great Lakes ecosystems is correlated in general with the population density in the area (Beeton 1969, Christie

Table 2.1. Some ecological features of the Great Lakes prior to degradation.

1. Differences in ionic composition of lake water between the lakes were not as marked as at present, both with respect to total ionic concentration and the mix of ions.
2. Little accumulation of organic sediments except in marshes, some bays and in some deep basins.
3. No anoxia in lake waters, except in some inshore lagoons.
4. Large areas of clay turbidity from bluff erosion much as at present, but much less elsewhere, e.g. in western Lake Erie.
5. Midsummer stream flows abundant with cool clear water.
6. Extensive wetlands, marshes and macrophyte beds.
7. Inshore waters of the open lakes likely cooler than at present; at least near cities and agricultural areas.
8. Organisms of large size dominant in many taxa, but likely not in the phytoplankton of the offshore epilimnion.
9. Numerous locally adapted stocks of salmonines and coregonines, and Atlantic salmon in L. Ontario.
10. Nearshore community mosaic luxuriant, abundant deep benthic community, rather sparse offshore epilimnetic biota.
11. No Pacific salmon, brown trout, rainbow trout, rainbow smelt, alewife, carp, goldfish, white perch and sea lamprey (although the latter may have occurred naturally in L. Ontario).
12. Populations (since extinguished) of unique species or subspecies of coregonines (chubs) and percids (blue pike), and salmonines (Michigan grayling) in portions of the basin.

1974). However, it is necessary to be more specific about causality than this. Major changes to Great Lakes ecosystems have resulted both from direct and indirect modifications of the biotic communities. We will deal first with chemical/physical modifications of the habitat and then the direct modifications of biotic communities.

As examples, we will consider phosphorus loading and microcontaminants as chemical modifications. The lakes differ greatly in the observed changes in concentration of dissolved ions (Figure 2.2). Lake Superior, with a large area and a small, relatively undeveloped forested drainage basin, has the lowest concentration of total dissolved solids. Both Lake Erie and Lake Ontario have experienced large increases in total dissolved solids and have been most negatively influenced by eutrophication and accumulation of chemical pollutants.

The increase in phosphorus loading to Lake Erie has been roughly proportional to the population increase in the basin which has been from approximately 3 million in 1900 to 13 million persons in 1975. The increased loading of plant nutrients to Lake Erie has altered the biota. Phytoplankton biomass has increased in the central basin (Davis 1964). Consequently, more organic matter settles into the bottom waters and increases the rate of oxygen depletion by decomposers. Surveys during 1973 and 1974 revealed that more than two-thirds of the central basin had no oxygen in its bottom waters (IJC Water Quality Board 1975). Zooplankton assemblages in the lower Great Lakes (Lakes Erie and Ontario) now contain more forms tolerant of eutrophic conditions than in the past. Open water zooplankton communities are still “healthy” while nearshore communities are significantly altered near the large cities and in the highly eutrophic inner bays (McNaught 1975). The benthic animal *Stylodrilus heringianus,* an oligochaete of oligotrophic lakes, is conspicuous by its absence in the areas of Lake Ontario near the large cities (Nalepa and Thomas 1978).

With increased eutrophication and human activity beaches collect the flotsam of civilization and the alga *Cladophora,* for example, becomes an especially noxious impediment to recreational use when it washes ashore and rots. Many miles of beaches in the lower lakes are lost to recreational use each year on this account (Neil 1976). Since 1958 in Lake Ontario essentially all suitable bottom in the photic zone supports a lush growth of *Cladophora* during the productive season. Shoreline accumulations of broken filaments sometimes reach 15 meters wide by 0.6 meters deep (Neil 1976). *Cladophora* problems in the lower lakes have no doubt affected shoreline property values as well as fouled public beaches. In Lakes Huron and Michigan *Cladophora* problems are localized. Only Lake Superior is essentially free of such problems.

Phosphorus loadings to the Great Lakes for 1976 (Table 2.2) show that Lake Erie receives by far the greatest proportion of the phosphorus input to the Great Lakes. Lake Huron receives the least, although Saginaw Bay receives much of this load and as a result shows severe signs of eutrophication. Normalizing the loading to lake surface area (Vollenweider 1968), which takes into account the widely different sizes and other properties of the lakes, even more dramatically demonstrates the great stress placed on Lakes Erie and Ontario in contrast to the upper lakes. Phosphorus from municipal wastes is the most important source,

Table 2.2. Total phosphorus loading to the Great Lakes in 1976 modified from the results of International Joint Commission Technical Group to Review Phosphorus Loadings (1978) and the International Joint Commission's Pollution from Land Use Activities Reference Group (PLUARG 1978). Total loading was estimated at about 57,000 metric tons per year. The percent to each lake and from various sources from the upper and lower lakes is given.

	Ontario	Erie	Huron	Michigan	Superior
Areal loading,* $g\ m^{-2}\ yr^{-1}$	0.55	0.76	0.09	0.12	0.05
% of total basin loading to each lake	17	44	8	18	13
% of total regional loading from each source					
Point	32			17	
Tributary, non-point	37			29	
Shore erosion	27			37	
Atmospheric	4			17	
	100			100	

*This includes input from upstream lakes but excludes erosion loads; these data were submitted by S. C. Chapra.

particularly in terms of the potential for rehabilitation. Runoff from land is also an important source of phosphorus, but, unlike point source, it appears based on recent information that less than half of this is in a form usable for plant growth (Armstrong et al. 1978, Logan 1978). Phosphorus also originates by natural processes such as shoreline erosion. However, much of this phosphorus is also in a form not available to support plant growth. Shoreline erosion is a good example of a natural process that has been going on for centuries. Atmospheric fallout of phosphorus is another important source. To large unproductive waters, such as those of Lake Superior, atmospheric contributions may actually be beneficial for those interests that benefit from higher ecological production.

Microcontaminants pose a major problem in the rehabilitation of Great Lakes ecosystems. The chlorinated hydrocarbons such as PCBs, DDT and Mirex are especially problematic because of their stability in the environment and because of their accumulation by fishes. Some lake trout in Lake Michigan contain 15-35 ppm of PCB, (Veith 1975, Weininger 1978). The latter makes them unfit for human consumption and consequently creates financial hardships for the fishers.

Contaminants appear to pose less direct problems for the fish themselves. In fact, when the western Lake Erie walleye fishery was closed in 1970 owing to mercury contamination, the lowered exploitation resulted in a rapid recovery of the population which had been over fished (Kutkuhn et al. 1976). In addition to the above compounds, other organic microcontaminants such as chlorophenols and also the other trace metals may cause problems in the Great Lakes.

The potential consequences of toxic doses of these substances to human health are so serious that control will most likely be enthusiastically supported by society. As a consequence, in the long run, some of the problems with synthetic microcontaminants may actually be resolved sooner than those of more commonplace industrial and domestic wastes, at least when and where the two types can be kept separate.

In March 1979 a workshop sponsored by the Great Lakes Basin Commission drew the following overall conclusion (GLBC 1979)

> "The scientific basis for dealing with toxic substances in the Great Lakes, including their effect on human health, is very limited compared to the magnitude of the problem. This is especially evident when the thousands of substances other than PCBs and DDT are considered. Planners, managers and the public, who must make decisions with regard to toxics, need to fully appreciate this limitation and the consequent uncertainty that will be inherent in many of their decisions."

The good news is that evidence (Fig. 2.3) is beginning to suggest that Great Lakes ecosystems may recover from toxic pollutants rapidly following abatement. The widespread use of DDT resulted in a high degree of contamination of Lake Michigan fishes during the 1960's. Following the DDT ban in 1970, total DDT concentrations (t-DDT) in coho salmon decreased rapidly, but they seem to be approaching a new level which is distinctly higher than zero (Fig. 2.3). Weininger (1977) spec-

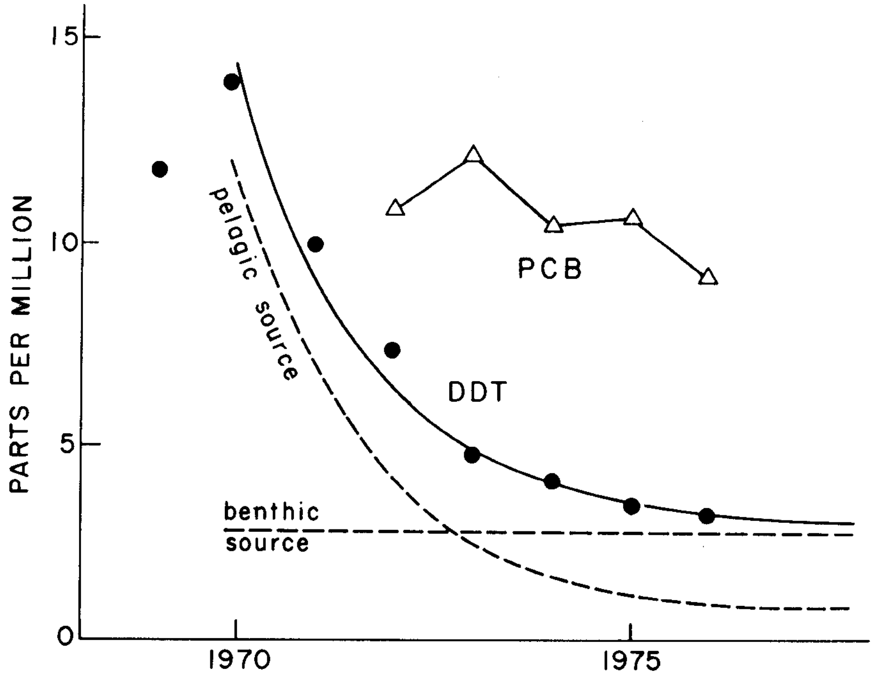

Figure 2.3. Concentrations of t-DDT and PCB observed in Lake Michigan coho salmon. Continuous line shows result of weighted nonlinear regression model; dashed lines show pelagic (decreasing) and benthic (constant) components based on a model with a presumed 1970 DDT input cessation. (Weininger 1979, personal Comm.).

ulated that these concentrations result from a two-part phenomenon. The rapid decrease reflects the removal of t-DDT from the water column which corresponds to the direct and pelagic food chain transport of t-DDT to coho salmon. The second part of the model reflects the benthic transport route. Since sedimentation rate in Lake Michigan is low and the age of the sediment mixed zone is high (Robbins and Edgington 1973) only a very slow decrease in this transport route is expected. The benthic pathway contribution is therefore modeled as being constant. In lakes where the sedimentation rate is low, the benthic pathway is expected to continue to make persistent contaminants available to the lake biota for a long time because contaminated sediments will not be buried rapidly.

The PCB levels in coho salmon have not declined as rapidly as the t-DDT levels (Fig. 2.3). Under the assumption of similar transport for both types of compounds, one may conclude that the input of PCBs to the Lake Michigan system has not been dramatically reduced despite the fact that the use of PCBs and DDT was limited at nearly the same time. DDT was banned from use in 1970; usage of PCB was partially curtailed in

1971-72. DDT-type substances were purposely used in the terrestrial environment in a controlled manner, while the PCB-type chemicals were introduced incidentally or accidentally. Large and readily available reservoirs of PCBs undoubtedly exist in the harbors, rivers, and drainage ditches of the Great Lakes, as well as in various dumps on land.

Physical modification of habitat has occurred in the rivers, harbors, bays, and inshore zone. There are many healthy and productive rivers around the Great Lakes. They tend to be the ones not subject to extensive urban influences. The most valuable of these have been trout streams and many have been radically altered by damming and deforestation.

The Ganaraska River (Richardson 1944) which flows into Lake Ontario shows a sequence of dam construction. The first ones were built by 1800. By 1860 there were 36 dams in this small basin. Sawmills were replaced by gristmills. Such dams significantly isolated the upper stream reaches from spawning migrations of Great Lakes fishes.

Rivers tend to be most affected near the mouths. Brook trout are seldom seen in the lower reaches of rivers in which they were once plentiful (Hallam 1959) because of warming effects. The tendency to build large cities at the mouths of rivers has had serious impacts. The Cuyahoga River at Cleveland is an obvious example. Floating oil released by industries has resulted in the river being considered as a major fire hazard. The problem reached such proportions that fire breaks were built to separate the surface waters into sections so that oil fires could be contained within a certain area (U.S. Department of Health, Education and Welfare 1965).

In the reach below the Southerly Plant, the Cuyahoga is grey, septic in the pools, and odorous. Transparency is reduced, and an oily brown scum is usually present. Cuyahoga water is almost totally devoid of oxygen during low flow summer months. Only a few sludgeworms and midge larvae were found in occasional riffles upstream. This reach of the Cuyahoga did not meet water quality criteria for any use (Simpson et al. 1968).

The Cleveland area has been identified as one of the "problem areas" in the Great Lakes basin and the major sources of pollution have been identified (IJC/Great Lakes Water Quality Board 1976, 1977, 1978). A great deal of money is being spent upgrading the unacceptable effluents from the industries there, but no appreciable improvements to the Cuyahoga have been observed in the biota (Great Lakes Water Quality Board 1976). The polluted lower reaches of rivers such as the Cuyahoga severely limit the habitat which the rivers could afford to migratory fishes.

The Maumee River is similar to other rivers flowing into the south shore of Lake Erie in that it is loaded with all types of pollution: industrial wastes, heat, sewage, pesticides and suspended sediment to name just a few. Until a hundred years ago, the Maumee flowed through the Black Swamp, an area of 7500 km^2 of flat lowland forest. The water leaving this area was clear. During the latter part of the 19th century, this swamp was drained and its ancient lacustrine soils were converted to fertile farm land. After cultivation of this watershed the river became highly turbid, a condition which has continued to this day (Verduin 1969). The load of sediment from this river to Lake Erie is presently estimated at 1,800,000 m tons annually (Kemp et al. 1978). At flood peaks in the winter and spring, the Maumee can discharge over 130,000 m tons of sediment per day (Herdendorf et al. 1977). Perhaps the most important effect of all is that the silt has covered the river and bay spawning grounds of such valuable fishes as sturgeon, lake whitefish and walleye, and has eliminated extensive beds of inshore rooted aquatic vegetation used by fish (Hartman 1972). Between the Huron River and Sandusky Bay there is currently little or no habitat suitable for spawning by northern pike and smallmouth bass (Jaworski and Raphael 1979b).

Harbors are typically also river mouths so they extend pollution influences well into the lakes. Pollution aside, shoreline modifications and dredging have profound effects and in many cases fish and wildlife habitat may never be recovered. The early Toronto harbor contained extensive marshes and beds of macrophytes which have been largely eliminated by dredging, siltation and shoreworks (Whillans 1977). Early fishing conditions described by Whillans were exellent. Today the harbor proper no longer supports quality fishing.

In the last century dredging for stone or "stone hooking" was an extensive practice in Lake Ontario (Whillans 1977). The practice extended over 75 years and employed as many as 40-50 ships along the northwest shoreline alone. The suspicion is that cobbly patches such as those used by whitefish and lake trout for spawning were prime targets for these operations and that this could have had serious impacts on fish recruitment.

Another modification of the physical habitat worth mentioning is the use of inshore water for cooling in connection with electric power generation. Entrainment and impingement losses are probably more important than the heating of the waters itself. Many native fish species in the Great Lakes have pelagic larvae and potential mortalities from entrainment need to be estimated and evaluated as impediments to restoration of fish stocks. On the positive side, lake trout have been using some of the shoreworks of power plants, e.g. at Marquette, Michigan, as spawning sites. This suggests that replacing cobble previously mined from Lake Ontario or construction of spawning sites could enhance reproduction of trout and whitefish.

In addition to habitat modification, direct and indirect modifications of the biotic communities have also been important. We already have mentioned that the fish taxa were probably represented by large individuals with as many at 50% of the biomass being of fish over 5 kg. The accumulated capital of the old fish was gradually exploited (mined) as was done with large trees on land. Thereafter, fisheries had to make do with the annual interest on a much diminished though much more productive capital stock. In the classical manner of a common property resource of limited scope, the gradually intensifying fisheries soon led to overfishing of the most preferred stocks. The capital stock of high valued fish species in the Great Lakes is now a small fraction-perhaps 5% of what it was in the Great Lakes of two centuries ago.

Significant changes have occurred in the fish stocks of all the Great Lakes. As with other elements of the biota, Lake Superior has had the least drastic changes. Lake Ontario was probably the earliest to be affected, followed by Lake Erie, Lake Michigan and Lake Huron. But even in Lake Superior the effects of man are apparent. By the late 1960s catches had dropped to 37% by weight and 31% by value of the early 1940s (GLBC/Fish Work Group 1975). Much of this loss was from the dramatic declines in catches of valued species such as lake trout and lake herring. Like many predators, the fishers switched to progressively lower valued species as prey.

The sea lamprey has been the most widely publicized cause of Great Lakes stock problems (Smith 1968, Lawrie 1970, Christie 1974). Penetrating to the upper lakes from Lake Ontario where it may have been native (Lark 1973), it brought about almost a complete collapse of the lake trout stocks in the upper three lakes by direct predation on the trout. In Lake Michigan the lake trout was extinct by 1956. The sea lamprey invasion resulted from the construction of the Welland Canal and was a direct result of the westward expansion of shipping to the Great Lakes region. While overfishing has seldom been clearly indicted in the *collapse* of Great Lakes fish stocks, it is believed to have exacerbated the effects of the sea lamprey. However, the loss of lake sturgeon and some stocks of whitefish were documented for the last century, before such factors as eutrophication and invasion or introduction of pest species like the sea lamprey became problems (Christie 1974).

Introduction and proliferation of exotic fishes like the alewife and the rainbow smelt have also shared the blame for stock losses (Smith 1970). The drastic impact of the alewife on virtually all fish species in Lake Michigan was documented by Wells and McLain (1972). Christie (1974) suggested that the proliferations of these pelagic species were possible owing to the virtual absence of predators in the lakes, since populations of the lake trout and burbot had collapsed owing to sea lamprey invasions. Dieoffs of the abundant alewives at the peak of their abundance (Colby 197 1) endangered water supplies and marred beaches for recreational uses. Alewife also influenced the entire food web through reducing the abundance of the larger zooplankton (Wells 1970) which in turn would also have modified the phytoplankton community structure (Shapiro et al. 1975).

Perhaps the best examples of rehabilitation of Great Lakes ecosystems came out of the events that followed sea lamprey and alewife invasions. These efforts were coordinated by the Great Lakes Fishery Commission. Initially weirs were constructed to prevent the spawning of sea lamprey in tributaries to the upper Great Lakes. Later, a toxicant called 3-trifluormethyl-4-nitrophenol (TFM) selective for ammocoetes was applied in streams where the young spent several years (Applegate et al. 1961). First treatments were to Lake Superior because the lake trout population there was still present although in reduced numbers. The program was successful and extended to Lake Michigan and Lake Huron. In addition, young lake trout were stocked to reestablish naturally reproducing populations. The lake trout survived and grew feeding primarily on alewife and smelt. At present there are large numbers of lake trout in the upper Great Lakes but to date almost no natural reproduction of introduced lake trout has been observed.

In further efforts to rehabilitate fish communities, the State of Michigan forged ahead with enhancement by stocking non-native salmonines to the lakes-namely, coho salmon, chinook salmon, steelhead trout, brown trout and Atlantic salmon. The purposes were both to crop the overabundant alewife and to provide a high value sport fishery in the region. The program was highly successful in Lake Michigan (Borgeson and Tody 1967; Borgeson 1970; Rybicki 1973).

Up to this point, we have been concerned primarily with the salmonines and their prey. However, the coregonines and percids also have had their problems. In Lake Michigan, the lake whitefish, lake herring, and chubs were in a depressed state in the mid-60s. Herring stocks have not responded to the fishery closures; perhaps the stocks were reduced to an irreversible low. Concern for the bloater, the surviving member of several species, mounted over the years (Moffett 1957, Smith 1964) to the point that special efforts were launched throughout the lake in 1975 to halt the slide into oblivion. Emergency orders were issued to mid-year by all states banning their commercial harvest except for a small assessment fishery under permit.

In Lake Superior, the only stable herring stock in 1972 was in Black Bay, Ontario. Chubs have also been on the decline, and a serious overfishing problem has developed for lake trout and lake whitefish in Whitefish Bay and certain Wisconsin waters due to unregulated fishing activities by native Americans. Again closures and quotas were applied by the states where feasible and possible. Minnesota initiated a fry-planting program in the French River to enhance recruitment of lake herring.

Lake Huron coregonine stocks suffered similar fates. Although herring and chubs continue to support a fishery in Canadian waters, stocks are very low on the Michigan side. Both species have been removed from the commercial list. The lake whitefish fishery in the southern part of the lake has been abandoned and gill nets are forbidden. However, a successful trap-net fishery exists in the northern Michigan waters as well as on the Canadian side. Commercially viable stocks of coregonines in the two lower lakes have since vanished.

Yellow perch and walleyes have supplied a significant sport and commercial fishery in many areas of the Great Lakes over the years. However, drastic fluctuations in abundance triggered a flurry of management activity among the agencies to remedy the situations with some success. In Lake Huron, Saginaw Bay holds the only Michigan perch stock subject to commercial netting. The perch stock in the western basin of Lake Erie is jeopardized.

Schneider and Leach (1977) reviewed the status of walleye stocks in the Great Lakes. Several populations have received considerable attention of late by management agencies in attempts to revive their sagging fortunes. By 1970, walleye stocks in the western basin of Lake Erie were in serious trouble, but a "fortuitous" closure of the fishery because of mercury contamination, followed by the institution of quota management at the urging of an international GLFC committee, has seemingly turned the situation around, even though one of the states involved greatly exceeded the quota. Saginaw Bay once supported annual commercial yields of about 7 million kg (Schneider and Leach 1977) but this vanished by 1950, due largely to a deteriorating environment plus exploitation and a moderate amount of lamprey predation. Recent attempts to revive the resource have failed.

Attempts to revive the depressed walleye fisheries in Green Bay and on the Muskegon River, a tributary of Lake Michigan, are also underway.

Conclusion

We have reviewed the original conditions of the Great Lakes and some of the factors causing change in Great Lakes ecosystems. Man has influenced and degraded both the habitat and the biotic communities. He has had some piecemeal successes in rehabilitation.

3. REHABILITATION METHODS

With the growing emphasis on rehabilitation and restoration of damaged ecosystems, it is not surprising that a large number of techniques have been considered, applied, and the results observed. In the previous chapter we pointed out a few of the successful ventures in the Great Lakes. Yet, most efforts have been applied on smaller inland lakes largely in the developed and populous countries in lake-rich parts of the world particularly within Austria, Canada, France, Switzerland, the United Kingdom, Germany, the Scandinavian countries and the United States. Among the most significant limnological efforts are those in Sweden (Bjbrk 1972; Bjork et al. 1972; Forsberg, Hawerman, and Ulmgren 1972; Forsberg, Ryding, and Claesson 1975), and the United States (U.S. Environmental Protection Agency 1973; Dunst et al. 1974; Edmondson 1973; Goldman 1974; Shapiro et al. 1975). Additional major publications include Seppanen (1973), Bjork (1974), Schindler and Fee (1974), Landner (1976), and Gelin (1978).

Most rehabilitation techniques have been developed in respect to a particular stress such as nutrient loading, overfishing, etc. Yet the different stresses interact in their effects on lakes and the rehabilitative techniques interact with each other and other stresses. The challenge is to develop and apply a mix of rehabilitative techniques to a mix of stresses relevant to a particular lake or bay or river mouth or shoreline. Application of the following methods is expanding rapidly and we will need to learn from others' experiences if rehabilitation of Great Lakes ecosystems is to succeed.

Rehabilitative methods are outlined below with respect to particular human-induced stresses with annotations on the stress and its manifestations, the rehabilitative methods and their application, and the technical, economic, and institutional feasibility of stress-specific rehabilitation.

The list of 18 categories of stress (Table 3.1) can be grouped in a variety of ways. We have chosen simply to list them. The first two have typically been the responsibility of fishery resource managers, three through six the responsibility of environmental agencies, and the remainder primarily in the realm of engineering agencies.

The outline below will serve as a rapid and abbreviated key to rehabilitative techniques that can be applied.

Fishing and other harvesting

Manifestations

A. Valued species

1. Almost all the large individual fish are fished out.
2. The mean age of fish in the catch approaches and may be reduced below the physiological minimum age of reproduction.

Table 3.1. List of human stresses on Great Lakes ecosystems

1.	Fishing and other harvesting of biota
2.	Introductions and invasions of exotic species
3.	Microcontaminants, toxic wastes and biocides, from industry and agriculture
4.	Nutrients and eutrophication from sewage plants, agricultural and urban run-off
5.	Organic inputs and oxygen demand from sewers, canneries, etc.
6.	Sediment loading and turbidity, from agriculture, construction sites, and resuspension
7.	Stream modification - dams, channelization and logging, changes in land use
8.	Dredging and mineral, sand, gravel, and oil extraction
9.	Filling, shoreline structure, offshore structure
10.	Water level control for shipping, electric power production, wetland management, etc.
11.	Dyking and draining of wetlands
12.	Weather modification, mostly industrial
13.	Water diversions between the Great Lakes basin and other basins
14.	Entrainment and impingement in water intake structures
15.	Thermal loading from cooling water, mostly in electric power plants
16.	Ice control for navigation
17.	Major degradative incidents or catastrophies
18.	Acids and toxic chemicals transported by the atmosphere

3. Year-to-year abundance of fish may fluctuate markedly due to annual differences in number of spawners, reproductive success, natural mortality, etc.
4. Some distinct stocks disappear permanently.

B. Changes in species composition
1. Dominance shifts from high-valued to low-valued species.
2. Dominance shifts from species that achieve large sizes to species that do not.
3. Dominance shifts from species that are long lived to those that are not.
4. Dominance shifts from benthic to pelagic species.
5. Dominance shifts from "k-selected" to "r-selected" species.
6. Dominance shifts from native to exotic species.

Rehabilitative methods

A. Regulate fishing
1. Set the minimum and/or maximum harvestable size of large, valued species.
2. Limit fishing intensity on valued species and stocks.
3. Regulate fishing practices to minimize the incidental capture of threatened stocks.
4. Employ fishing methods that do not seriously disrupt natural migratory and spawning behavior of "escapement components" of stocks.
5. Encourage, if necessary through subsidy programs, selective fishing on low-valued species currently at undesirably high levels of abundance.

B. Increase recruitment
1. Enhance reproduction of desired stocks, if necessary through artificial reproduction.

C. Introduction of species
1. Re-introduce and establish close relatives of extinct stocks such as lake trout and/or introduce valued "k-selected" exotics.

Feasibility

A. Technically feasible and being implemented, at least in ad hoc, piecemeal fashion.

B. Economically feasible, at least if commercial fishermen are assigned de facto, limited property rights; and if the regulations are formulated to achieve ecological and economic goals in a way other than through enforced technical inefficiency.

C. Institutionally there are great problems in achieving balanced, integrated regulation because of the intense and often misguided conflict between different groups of fishermen. The endangered species act has a yet unknown relation to species and stocks heavily stressed by fisheries.

Selected references

Van Oosten et al. (1946), Baldwin and Saalfeld (1962), Dymond (1964b), Smith (1968), Regier and Loftus (1972), Gulland (1977), Larkin (1977), Spangler et al. (1977), Christie (1978b).

Introduction and invasions of exotics

Manifestations

A. Introduced by government fisheries workers
   1. Carp have acted to the disadvantage of esocids and other species in shallow muddy waters and have expanded into a food niche vacated by the lake sturgeon which was severely overfished.
   2. Rainbow trout have expanded into the niche vacated by endemic Atlantic salmon in Lake Ontario, and occur in comparable poorly exploited niches in the other lakes.
   3. Rainbow smelt escaped into Lake Michigan from a small inland lake into which they were introduced. They have become very abundant in some of the Great Lakes and may occasionally prey on pelagic eggs and larvae of valued coregonines and percids.
   4. Brown trout were introduced to supplement the endemic speckled trout, and modest populations occur in some streams.
   5. Small species of Pacific salmon were introduced to utilize zooplankton and thus to compete with low valued, exotic pelagic planktivores. The pink salmon is currently spreading throughout the Upper Lakes.
   6. Large species of Pacific salmon were introduced to utilize a large pelagic biomass of small fish species, most of which were non-endemic.

B. Invaded through canals
   1. The sea lamprey reached the upper lakes and preyed heavily upon lake trout, lake whitefish, burbot, walleyes, suckers and other species.
   2. The alewife expanded to large populations in all lakes except Lake Superior and successfully competed for plankton forage with native coregonines, percids, and minnows (cyprinids).
   3. The white perch is currently spreading but has not as yet had a major impact.

C. Released with bilge water
   1. *Eurytemora affinis,* a brackish-water calanoid copepod, now constitutes 1-2% of the zooplankton biomass in Lake Ontario.
   2. The Chinese mitten crab now occurs in western Lake Erie where it may be destructive of littoral vegetation.
   3. *Bangyia,* a marine red algae, now occurs in some eutrophic parts of the Great Lakes, where its ecological impact is unknown.

D. Released by aquarists
   1. The goldfish is abundant in some shallow inshore areas where it hybridizes with carp.

E . Pathogens
   1. Exotic pathogenic organisms usually invade the lakes along with their exotic hosts.

Rehabilitative methods

A. Prevent introduction and reproduction of unwanted exotics
   1. Tighten controls on introduction of new species.
   2. Interfere with recruitment of unwanted exotics.

B. Increase mortality on unwanted exotics
   1. Supplement recruitment of predators on unwanted exotics.
   2. Introduce predators that would prey on unwanted exotics.
   3. Introduce pathogens that would infest unwanted exotics.
   4. Develop and subsidize increased selective fishing on unwanted exotics of little sport or commercial value.

Feasibility

A. Technically the eradication of sea lamprey seems impracticable but effective control with the selective toxicant TFM is practical. Salmonids can apparently be reared and stocked in sufficient numbers to suppress greatly the abundance of clupeids and osmerids and intense selective fishing could probably achieve the same effect. Measures to control access of new species through existing canals or via bilge water are not developed. The use of parasites for biological control has not been developed, though it was briefly considered for sea lamprey control.

B. Economically there is some question whether sea lamprey control is worthwile. Exotic salmonids could readily be controlled through unregulated fishing. It would be very costly to attempt direct control of small pelagic species.

C. Institutionally all governmental controls on entry by exotics are as yet relatively ineffective. Sea lamprey programs and hatchery programs have institutional homes.

Selected references

Applegate (1950), Maher (1964), Tody and Tanner (1966), Loftus (1968), Smith (1968), Lawrie (1970), Christie et al. (1972), Nepszy and Leach (1973), Christie (1974), Magnuson (1976).

Microcontaminants: toxic wastes and biocides

Manifestation

A. Direct effects on biota
   1. Lethal concentrations associated with spills or unregulated discharge cause fish kills.

2. Bioaccumulation of microcontaminants produce sublethal effects on growth and reproduction and thus lower the biological productivity of less tolerant organisms.
3. Microcontaminants aggregate in the sediment and are recycled into fauna via benthic food webs.

B. Direct effects on humans

I. Owing to real or perceived health hazards fish are designated as unfit as human food.
2. Commercial fishers, processors, and dealers incur direct economic hardships.
3. Sport fishers either are not allowed to fish or more frequently are warned to eat their catch infrequently.

Rehabilitative methods

A. Control input to lake ecosystem
1. Prevent input of new hazardous substances.
2. Reduce input of existing compounds to acceptable levels.

B. Remove hazardous substances from further contact with organisms
1. Enhance storage of microcontaminants in sediment in area of deposition.
2. Extract contaminated sediment in more erodable deposits.
3. Exploit and remove contaminated organisms.

C. Alter harvest strategy
1. Harvest species with low levels of microcontaminants acceptable for human consumption.
2. Harvest contaminated species at smaller (younger) sizes before contaminants accumulate at unsafe levels.

D. Reduce bioaccumulation
1. Alter community structure of forage fishes to more bioenergetically efficient species or species less dependent on the benthic food web to reduce bioaccumulation of microcontaminants in edible species.

E. Reduce microcontaminants during food preparation
1. Process or prepare contaminated fish for consumption in a manner that reduces contaminants to acceptable levels.

Feasibility

A. Technically some of the methods are feasible, others are untested. Feasible procedures include controlling the input of hazardous substances, altering harvest strategies, extraction of contaminated sediments, and cooking products with fat soluble contaminants in ways that separate the fat from the flesh. Methods to enhance storage in sediments and reducing bioaccumulation by altering community structure are untested or undeveloped. Removal of contaminated fishes removes only a small quantity of microcontaminants present in the ecosystem.

B. Economically the feasibility is untested or not yet estimated. Benefits of maintaining valued fisheries seem high.
C. Institutionally there are established agencies of pollution control of microcontaminants and regulation of fishing. Institutional arrangements for more integrated approaches of fishing management and pollution management are absent or weak.

Selected references

Veith (1975), Haile (1977), IJC/Great Lakes Water Quality Board (1977), Flotard (1978), Weininger (1978), Armstrong et al. (1978), IJC/PLUARG (1978), IJC/RAB (1978), Great Lakes Water Quality Agreement (1978), Pazik (1979), Sonzogni (1979), Johnson and Berg (1979),

Nutrients and eutrophication

Manifestations

A. Plant growth
   1. Dense blooms of bluegreen and green algae grow and decay in water column.
   2. *Cladophora* mats pile upon rocks and beaches.
   3. Rooted macrophytes are reduced in mass and diversity by shading and nutrient competition.
   4. Decaying algae reduce dissolved oxygen beneath the thermocline in summer and near bottom during winter.
   5. Algae cover rock and sandy areas used for fish spawning.

B. Animals
   1. Composition of zooplankton and benthic organisms change to those more tolerant of low oxygen or altered availability of algal food.
   2. Fish composition changes to those more tolerant of low oxygen or those less dependent for spawning on well washed gravels and sands.
   3. Total yields of cold water species decline as hypolimnion goes anoxic and spawning sites degrade.
   4. Total yields of warm and cool water fishes probably increases moderately.

Rehabilitative methods

A. Reduce inputs of phosphorus
   1. More effectively separate storm and sanitary sewers.
   2. Limit phosphorus release at sewerage treatment plants.
   3. Limit phosphorus content in detergents.
   4. Improve agricultural practices to reduce loss of nutrients.
   5. Intercept nutrients in marshes or reservoirs on streams.

B. Modify habitat
   1. Dredge bays in restricted areas.

C. Manipulate biotic community
   1. Pathogens may exist for some of the more noxious algae or macrophytes.
   2. Altering the abundance of certain zooplanktivorous fishes may alter food webs in ways that would favor green algae over the more noxious bluegreen algae, or may increase zooplankton grazing on algae with the effect of reducing some bad features of excessive nutrient additions.

Feasibility

A. Technically the reduction of phosphorus is feasible and is being implemented. Deepening is feasible for small selected portions of bays but not for larger areas. Most other techniques used in small lakes such as drawdown, nutrient inactivation, lake bottom sealing do not appear feasible. Manipulations of biotic communities to reduce the unpleasant effects of nutrients are in the research stage and may be feasible in the future.

B. Economically the feasibility is apparent for many point sources and for improved agricultural practice.

C. Institutionally, it is feasible for point sources and is being implemented.

Selected references

Beeton (1965), Lee (1971), Beeton and Edmondson (1972), Colby et al. (1972), Vallentyne (1974), Schindler and Fee (1974), Vollenweider et al. (1974), Dunst et al. (1974), Shapiro et al. (1975), Neil (1976), Landner (1976), Leach et al. (1977), Nicholls et al. (1977), Sonzogni et al. (1979).

Organic inputs and oxygen demand

Manifestation

A. Localized anoxic conditions
   1. Use of streams for fish spawning migration can be effectively blocked at mouth.
   2. Loss of habitat for aerobic organisms such as fishes and for fish eggs to develop on bottom.

B. Fiber
   1. Wood fiber irritates and abrades fish gills.

Rehabilitative methods

A. Improved waste treatment
   1. Remove particulates from waste discharge.

B. Seal existing sediments which have high oxygen demand
   1. Cover with relatively inert material such as sand.

Feasibility

A. Technically it is feasible as new methods are being developed to improve waste treatment.

B. Economically the feasibility is unknown. Benefits through fiber recovery have some potential.
C. Institutionally the responsibilities among agencies are already clarified.

Selected references

Colby and Smith (1967), Adelman and Smith (1970), GLBC/Water Quality Work Group (1975), Bertrand et al. (1976), IJC/Great Lakes Water Quality Board (1978), Born (1978).

Sediment loading and turbidity

Manifestations

A. Burial of existing substrates
   1. Rock and gravel substrates suitable for fish spawning in streams and inshore areas are lost.
   2. Distributions of macrophytes and benthic fauna are altered.

B. Increased turbidity
   1. Primary productivity decreases owing to reduction in the phototrophic zone.
   2. Effectiveness of visual predators such as fish is reduced.

C. Contaminated sediment
   1. Toxicants brought in with sediment.

D. Resuspension of sediment
   1. Activities of boats in shallow water, storms, and construction activity increases turbidity and re-exposes contaminated sediment to water column.

Rehabilitative methods

A. Reduce input of inorganic particulates
   1. Improve soil conservation practices.
   2. Control runoff from construction sites.
   3. Control forestry practices.
   4. Implement reforestation and shoreline stabilization.
   5. Control forest fires.
   6. Treat or prevent waste discharge.

B. Reduce resuspension of sediments
   1. Dredge sediments and remove from sites susceptible to re-suspension.
   2. Seal fine sediments with sand cover.

Feasibility

A. Technically it is feasible to reduce the inputs of sediment. In some cases land disposal sites are required for industrial inorganic particulates. Resuspension processes can be controlled.
B. Economically the feasibility is site specific and undetermined.
C. Institutionally many agencies have responsibilities.

Selected references

Langlois (1945), Van Oosten (1948), GLBC/Erosion and Sedimentation Work Group (1975), Bertrand et al. (1976), Day et al. (1977).

Stream modification: dams, channelization, logging, and changes in land use

Manifestation

A. Damming
1. Migrating fishes are blocked.
2. Water temperature increases.
3. Stream spawning areas are covered by standing water impoundments.
4. Nutrient, sediment, and organic input to lake from the streams are reduced.
5. Hydraulic regime altered, often adversely.
6. Stream bed not flushed by annual flood, dry in midsummer.

B. Channelization
1. Spawning habitat is lost.
2. Nursery areas in streams are lost.
3. Biological productivity of stream is greatly reduced.

C. Logging and land use
1. Water temperatures are increased.
2. Erosion of sediments, organics, and nutrients are increased.

Rehabilitative methods

A. Effect of dams
1. Do not build additional impoundments.
2. Remove some existing dams.
3. Construct artificial spawning channels.
4. Provide fish passage facilities.
5. Retain sediment in impoundment on the watershed.

B. Effects of channelization
1. Prevent additional channelization projects.
2. Require sound stream bank management.
3. Allow streams to return to more natural channel morphology.

C. Effects of logging and land use
1. Maintain an undisturbed margin alongside all streams.
2. Reforest stream banks that have been logged or farmed.

Feasibility

A. Technically the projects are feasible but dam removal also has negative effects such as providing spawning stream access to sea lamprey and smelt.

B. Economically the feasibility needs to be determined at each location.

C. Institutionally the responsibilities are complex owing to problems with ownership.

Selected references

McCombie (1968), Hynes (1970), Ryder and Johnson (1972), Osborn and Allman (1976), Cairns et al. (1977).

Dredging and mineral, sand, gravel, and oil extraction

Manifestation

A. Resuspension of sediment
   1. Dredging and mining activities increase turbidity.
   2. Dredging and mining cause release of contaminants.
   3. Dredging and mining blanket nearby areas with sediment.

B. Loss of existing substrate
   1. Remove rock and gravel of spawning reefs.
   2. Burial of spawning habitat by deposited spoil.

Rehabilitative methods

A. Resuspension of sediments
   1. Confine suspended materials to a very local area with curtains or buffers around dredging and construction sites to prevent current action and allow materials to resettle in place.
   2. Hydraulic dredges plus dewatering systems with transport to a terrestrial containment site, or beneficial use in lake or to open lake disposal for relatively unpolluted materials.
   3. Control of water flow and nutrient removal from water at certain dredge disposal sites.

B. Removal of valuable sediment habitat
   1. Exclude disturbance of spawning sites or potential spawning substrates.
   2. See filling, shoreline structures, offshore structures below.

Feasibility

A. Technically the methods are developed or being developed.
B. Economically the feasibility must be judged at individual sites.
C. Institutionally the agencies are in place.

Selected references

Windom (1972), IJC/Abatement and Control of Pollution from Dredging Activities Work Group (1975) Herbich (1975), Owen (1977).

Filling, shoreline structure, offshore structure

Manifestation

A. Major alteration of the hydrodynamic environment
   1. Breakwaters, jetties, piers, etc., interrupt along shore sediment transport, starve down-current beaches, and result in shore erosion.

2. Increase or decrease in currents and their transport of suspended and dissolved materials.
3. Breakwaters or offshore islands intercept wave energy, alter waves on the shoreline, and thus alter sediment size (sand to silt), beach slope, and along-shore currents.

B. Altered habitat
1. Habitat alteration permits new assemblages to move in to an area.
2. Habitat alteration eliminates some species from the area.

Rehabilitation methods

A. Creation of new habitat
1. Rock riprap at construction site can be used as spawning substrate for fishes.
2. Artificial islands can act as confinement locations of contaminated substrate, as well as be constructed such that they can be bird nesting areas and littoral zones of value.
3. Careful design of island shape and slope can maintain current and wave patterns that will favor natural restorative processes to form wetlands, littoral zones with macrophytes or beaches as desired.
4. Subsurface reefs could also be developed where contours had been obliterated over time.

Feasibility

A. Technically such measures will require careful preplanning and will constitute experiments in the real world.

B. Economically such measures will probably be feasible because, if well planned and executed, benefits would accrue to both the engineering project and the environment.

C. Institutionally many agencies would be involved and responsibilities would be diffuse and complex.

Selected references

Day et al. (1977), Nelson and Needham (1979).

Water level fluctuations and control

Manifestations

A. Natural fluctuations in the Great Lakes
1. Seiche fluctuations depend on basin morphometry and weather events. They can produce substantial fluctuations, e.g. Green Bay fluctuations typically over 11 hours cause as much as 0.75 m change in water levels.
2. Periodic fluctuations result in high and low water years. Winter storms during high water years can result in considerable shore erosion and property damage.

3. Fluctuations associated with long-term climatic changes are irregular, but can be very large, i.e. up to 1.5 m or more.
4. Annual fluctuations of about 0.3 m are regular and relatively long term, reaching a seasonal low in December or January and a high in May or June.
5. Fluctuations due to tides are very small and predictable.

Rehabilitation

A. Some control of lake levels on Lake Superior has been exercised since 1923 at the Sault Locks and of levels in the lower lakes at the outlet of Lake Ontario since the mid-1950's under the supervision of International Boards of Control reporting to IJC. Studies are currently underway to examine the engineering feasibility of similar controls at the outlet of Lake Erie (IJC 1977).

B. Shoreline protection structures such as dykes, groins (see: Filling, shoreline structures, etc.). Long-term effects on wetlands protected in this way may be detrimental since these ecosystems are adapted to natural stresses from water level fluctuations and may operate on a "pulse stable" basis.

C. Proper shoreline uses and zoning to remove development from flood-prone areas.

Feasibility

A. Technically it is doubtful that further reduction in overall Great Lakes level fluctuations by engineering control works is feasible. Diked coastal marshes can be maintained but may not be desirable in the long run, since wetlands benefit from some instability. Shoreline property protection by structural works is often poorly planned, and create worse erosion problems along shoreline property "down-current."

B. Economically the feasibility is often questionable. Issues are unresolved about compensating owners of property damaged in part by water held at artificially set levels.

C. Institutionally the coordination for proper shoreline/coastal zone management is difficult due to multiplicity of private owners and government agencies.

Selected references

GLBC/Levels and Flows Work Group (1975), Good et al. (1978), Geis (1979 MS).

Dyking and hydrologic modifications of wetlands

Manifestations

A. Hydrologic modifications
   1. Loss of hydrologic connectivity between coastal habitats.
   2. Reduced interchange of littoral and wetland water masses, especially at low Great Lakes water levels.

3. Reduction in allochthonous sediment trapping and nutrient uptake capacity.
4. Interruption of detrital exportation into the Great Lakes.

B. Changes within the dyked wetlands
1. Loss of fish populations except for tolerant, warmwater species.
2. Reduction in the pulsing of vegetation succession, and invasion of weedy plants along dykes and within managed wetlands.
3. Dissolved oxygen deficiencies and extreme water temperature fluctuations are common, especially during the winter.

C. Ecological changes
1. Fragmentation of habitats within the coastal zone.
2. Reduction in multiple use and species diversity of dyked areas.
3. Less total spawning and nursery habitat available to wetland-dependent fish stocks.
4. Dyking reduces the quality and availability of invertebrates, e.g., insect larvae and amphipods, to forage minnows and other Great Lakes fish.
5. Dyking and drainage alterations stimulate land development.

Rehabilitative methods

1. Remove earthen dykes on publicly-owned wetlands so as to allow wetlands to shift laterally during lake level fluctuations. (Only 10% of Canadian wetlands are dyked as compared to 40 to 60% on the USA side).
2. Modification of breakwaters, jetties, bridges, and rip-rap erosion control structures to allow hydrologic connectivity.
3. Redesign artificial drainage canals so as to disperse runoff water and suspended solids along the landward margin of the wetlands.
4. Implement areawide water quality management controls to reduce sediment and nutrient loading of wetlands from developed, terrestrial areas.
5. Regulate future construction of canals across coastal wetlands.
6. Create wetlands artificially along extensively developed coastlines.

Feasibility

A. Technically various methods of rehabilitation appear to be feasible but have not been well-tested in the Great Lakes.

B. Economic studies have not been carried far with Great Lakes wetlands.

C. Political and institutional feasibility hinges on the following considerations:

Support data are needed to convince public wetland managers that open wetlands are more productive, in the long run, than dyked wetlands. Modification of existing hydrologic barriers and drainage obstructions is not likely except during repair or replacement. Current federal wetland and state shorelands management legislation should prohibit inadequately designed drainage modifications in the future. Management of coastal watersheds to reduce sediment and nutrient loading of Great Lakes wetlands appears to have been given low priority by the International Joint Commission. Except for the creation of wetlands by the U.S. Army Corps of Engineers at Pointe Mouillee, Michigan, preservation of the base is the main wetland strategy.

Selected references

U.S. Dept. of Interior (1967), Verduin (1969), U.S. Army Corps of Engineers (1974), Jaworski and Raphael (1976), IJC/PLUARG (1978), Tilton et al. (1978), Jaworski and Raphael (1978, 1979a, b), SEMCOG (1978, 1979), and Sparling and Barr (1979).

Weather modification

No significant weather modification activities are now underway in the Great Lakes region nor do we know of any plans to attempt weather modification which might affect the Great Lakes. Inadvertent weather modification may be going on in urban or industrial centers, but the effects are not well understood except for "heat islands" associated with large cities. Too little is known about weather modification to assess any possible effects on the Great Lakes. Feasibility is unknown.

Water diversions

Manifestation

A. Few diversions at present
   1. Presently authorized water diversions within the Great Lakes basin have no known significant overall impacts on the Great Lakes themselves, but the inorganic turbidity has increased in large parts of Lake Nipigon.
   2. Presently authorized diversions into the basin from James Bay drainage and out of the basin to the Mississippi River drainage are sufficiently counterbalancing to have no significant overall impacts on water levels.

B. Large scale diversions into and out of Great Lakes basin have been proposed from time to time, especially during the 1960's. The overall feasibility of these have yet to be established.

Rehabilitation

A. Not needed at present time.

Feasibility

A. Technically it is feasible to divert large quantities of water into and out of the Great Lakes basin, e.g. from Hudson Bay and James Bay drainage and to Mississippi, Hudson River drainages, etc.

B. Economic feasibility is highly questionable.
C. Political feasibility is highly questionable.

Selected references
Krishner (1968) Bridger (1978), Peet (1978).

Entrainment and impingement

Manifestations
A. Fishes
1. Large fish of species such as gizzard shad, alewife, smelt and yellow perch are impinged on screening devices and generally killed.
2. Fish eggs and larvae are swept through the plant and generally killed.
B. Algae and zooplankton
1. Some fraction of entrained zooplankton, perhaps less than 10%, die of injury.
2. Phytoplankton are little damaged.

Rehabilitative methods
A. Intake structures
1. Techniques used to date to keep organisms away from the intakes and screens are inadequate.
B. Intake location
1. Intakes may be placed where few organisms occur naturally, perhaps offshore at several depths alternated with time of day or season.
2. Intakes and outfalls should be located to prevent the occurrence of recycling gyres by which warmed water reenters the intake.

Feasibility
A. Technically, serious problems remain.
B. Economically, serious problems remain.
C. Institutionally the industry is generally unimpressed with ecological concerns and in some jurisdictions still have political power to put-off effective study and, of course, action.

Selected references
Van Winkle (1977), Kelso and Milburn (1979).

Thermal loading

Manifestations
A. Altered fish behavior
1. Warm water attracts some fish species into the outfall area making them more vulnerable to the intake.

2. New fishing areas develop for anglers using stocks attracted by the warm temperature.
3. Thermal plume may form a possible barrier to migrating fish that normally use natural temperature and current cues.

B. Warm water habitat
1. New spawning and summer habitat for species such as smallmouth bass near the northern edge of their range.
2. Warm water refuges for carp are formed in relatively cool areas.

Rehabilitative methods

A. Temperature
1. Use of large volumes of water to minimize the difference in temperature, AT, due to heat loading but this exacerbates impingement.

B . Location
1. Place the outfall at some distance from shore to prevent the thermal plume from acting as a barrier to along-shore migration.
2. Use a closed system with cooling pond or towers rather than an open system.
3. Use the waste heat for beneficial purposes so as to reduce the AT farther.

Feasibility

A. Technically feasible but not being implemented.
B. Economically all measures currently are too costly.
C. Institutionally the industries causing waste loading are powerful politically.

Selected references

Denison and Elder (1970), Emery and Loftus (1972), Utility Water Act Group (1978).

Ice control

The results and ecological effects of modification of ice regimes are being extensively investigated by the U.S. Corps of Engineers in two somewhat separate projects, the Demonstration Program and the Extended Winter Navigation Feasibility Study, which were authorized by the River and Harbors Act of 1970 and the Water Resources Acts of 1974 and 1976. Final reports and recommendations are to be submitted to Congress in December of 1979. The U.S. Fish and Wildlife Service, through an interagency agreement with the Corps, developed an Environmental Plan of Action recommending which studies need to be done (including methodologies and procedures to establish baseline environmental information).

In view of these ongoing comprehensive studies little of a substantive nature can be said in this report. In brief, it is expected the main effects of ice control to extend the navigation season will be on the shoreline and littoral communities in the interlake connecting passages and the St. Lawrence River. Assessment of the feasibility of measures to prevent damage to ecosystems must await identification and evaluation of the deleterious effects.

Selected references

Botts (1979), Lin and Gregerman (1979).

Major degradative incidents

Manifestation

A. Damages due to severe storms can be especially heavy during high water periods (see: Water level fluctuations).
B. Major spills of hazardous materials from onshore storage facilities or shipping. Loss of radioactive materials from nuclear plants.
C. Illegal disposal of liquid industrial wastes into sanitary sewers, with subsequent failure of municipal facilities.
D. Leakage of highly toxic wastes from old dump sites at unknown or secret locations.
E. Accidental introduction of exotic pests and pathogens that then spread throughout the Great Lakes system (see: Fishery management).

Rehabilitation

A. Contingency plans to deal with accidental spills, such as the CANUSLAK arrangements maintained by the Coast Guards of both countries, need to be maintained or strengthened where necessary.
B. Strengthening of surveillance and enforcement measures over the use, transportation and disposal of toxics and other hazardous materials.
C. Research and development of alternative industrial processes to phase out use of the biologically more hazardous materials.
D. Implementation of "user pay" or "abuser penalty" type mechanisms to recover costs of rehabilitative measures.
E. Strengthen the process by which proponent agencies submit "prospectives" on proposed introductions of new species and seek concurrence of all other agencies around the Great Lakes; enforce existing laws on the subject.

Feasibility

A. Technically the feasibility is in most cases sufficient for specifying the precautionary measures needed. Chemical composition of materials in waste sites is not always known.
B. Economically the feasibility will be judged negatively by chemical industry in business economic terms, and by major users if they are held liable for damages. Inspection and other "policing" costs

would increase for environmental agencies. Consumer acceptance of substitutes involving fewer hazards in production processes may be less.

C. Institutionally there are problems posed by practice of allowing industrial and commercial interests to treat data on chemical composition of hazardous materials as trade secrets. Allegations recur about falsification of records on waste disposal by commercial haulers and/or public officials. Current public mood against "big government" hampers strengthening of environmental control agencies and permits weak policy and lax enforcement to continue.

Selected references

Kates (1978), Hall (1978), IJC/PLUARG (1978), Great Lakes Water Quality Agreement (1978), Perkinson (1979), Burton et al. (1978).

Acid precipitation

Manifestations

A. Waters that naturally have low alkalinity are particularly susceptible to acidification, e.g. those of the La Cloche Mountains north of Georgian Bay. Recent annual loadings as sulfuric acid in some susceptible areas are now about 2 g m^{-2} or 20 kg ha^{-1}, and some lakes have responded markedly (Figure 3.1). In general the lakes and rivers of the Laurentian Shield are susceptible except in small areas in which some calcareous rocks occur.

B. Many acidified lakes have lost fish populations, usually through failure of reproduction and recruitment. Lake trout, walleye, lake herring, smallmouth bass and other species have disappeared from the La Cloche lakes.

C. Streams and rivers originating in acid stressed areas may be seriously acidic, e.g. with pH below 5 during the peak discharge period in spring. Some inshore waters of Georgian Bay now have lower pH than normal. It may be that some stream spawning stocks of this area that waned during recent years may have been adversely affected by the acidity.

Rehabilitative methods

A. Acidic smoke from ore sintering, smelting, burning of fossil fuels and other sources will need to be reduced not only in the Great Lakes basin but for distances greater than 1000 km to the west and south, in order to reduce significantly the overall rate of acid loading.

B. Sweden is liming acidified waters on a large scale but only as a stop-gap measure to save valuable fisheries pending some better solution to the problem. In some waters liming using industrial materials elicits some of the undesirable ecological responses usually associated with eutrophication.

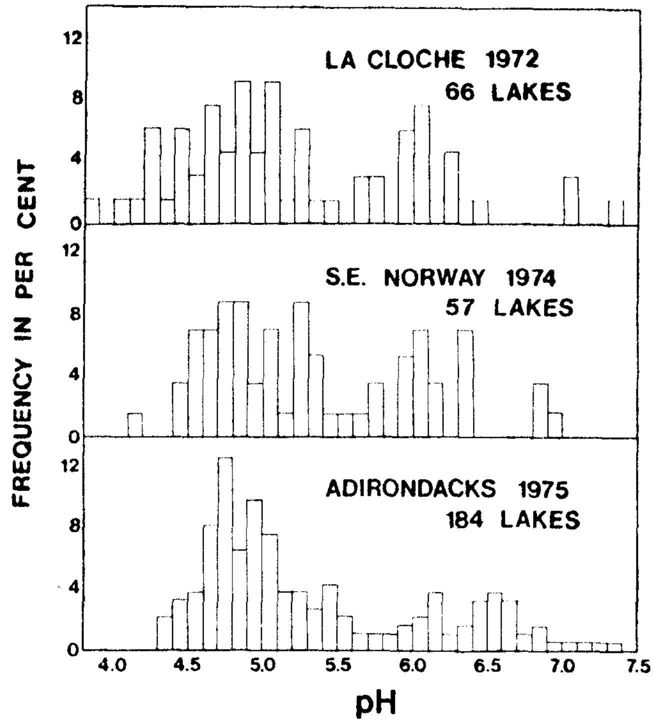

Figure 3.1. pH distributions of three groups of acidified lakes. Source: La Cloche, Harvey, 1975; Norway, Wright et al., 1977; Adirondacks, Schofield, 1976.

C. Acid-resistant stocks of fish could perhaps be bred for waters in which the acidification sequence can be halted and stabilized before some ultimate physiological threshold is transgressed. But individual species may only possess a small degree of plasticity with respect to any acidity threshold.
D. With reversal of acidification following the loss of some local populations, a re-introduction of appropriately pre-adapted stocks may be attempted. Repeated attempts will be necessary in some cases based on analogous experience with recovery following relaxation of other stresses. Even with a successful introduction closer adaptation of a particular stock to the habitat and a reconstitution of a normal, stable fish community would likely require a couple of decades.

Feasibility

A. Technically the control of acid loading from point source and automobile emissions is feasible. On a local level acidified waters can be neutralized with alkaline materials, though apparently not without triggering some other ecological responses.

B. The economic costs of controls on point source and automobile emissions as well as of local alkaline treatments are all quite high. The costs of spreading alkaline materials rather evenly over millions of hectares of susceptible areas now subject to acidification would be exorbitant.

C. Institutionally the ostensibly responsible agencies of all the jurisdictions that need to become involved with this problem have exhibited excessive inertia on acidification. The overall dimensions of the problem were already reasonably clear about 1970. Recently some still very modest research expenditures have been authorized, but no effective institutional response is yet apparent.

Selected references

Oden (1968), Harvey (1975), Schofield (1976), Wright et al. (1977), IJC/Science Advisory Board (1979).

4. SOCIO-ECONOMIC FEASIBILITY OF REHABILITATION

Earlier chapters have summarized the major categories of physical and biological changes or stresses on Great Lakes ecosystems which tend collectively to reduce their ecological, recreational, and aesthetic integrity and/or utility. They also identified various measures which could be taken to remove or ameliorate these conditions, as well as some of the results which could be expected from implementing these measures. We come now to a different question: To what extent are rehabilitation efforts justified on economic grounds? In simpler terms, will rehabilitation have a positive economic payoff and how could this be determined?

We shall address this question from a broad socio-economic point of view. That is to say, we will not be concerned about which rehabilitation efforts will provide positive profits to particular individuals or private corporations. Rather, we will look to the overall gains and losses to society generated by rehabilitation efforts. "Society" is taken here to mean the citizenry of the United States and Canada.

We present first a brief explanation of benefit-cost concepts to help interpret what follows. Then we examine particular benefits and costs associated with various rehabilitation measures. Finally, we summarize available data in order-of-magnitude figures. The chapter arrives at two conclusions. First, a great deal is *not* known about the benefits and costs of rehabilitation measures. Second, however, it is readily apparent that some degree of rehabilitation is highly beneficial.

Benefit-cost concepts

When we ask whether the benefits of rehabilitation will exceed the costs, what are we really asking? One answer is that we are asking whether, over the long run, the "gainers" (those who benefit from the change) would, if called upon to do so, adequately compensate both the producers (those who provide the labor and other resources for the change) and any "losers" (those who feel worse off as a result of the change). It is basically the same question you ask yourself when you decide whether you should purchase a given product in the market. If you voluntarily purchase something at a given price, you do so because you think you will be better off with the product, and your payment will have compensated the producers. The main difference is that the beneficiaries of public decisions may not be the only ones who pay the costs. Producers and "losers" would be "adequately" compensated when they feel at least no worse off after the change has been produced and compensation has been paid, than they were before. Therefore, economists look for two things: the benefits, measured in terms of how much the public would be willing to pay; and the costs, measured in terms of adequate compensation.

If long run benefits exceed long run costs, the project is probably a good choice (unless even better choices are available) for society because in an important sense the social gains outweight the social costs: a gain in aggregate welfare for society. We can feel confident of that because we know that if compensation were paid no one would be worse off and at least some members of society would be better off. These gains and losses can also be assessed in ways other than through economic analysis (such as through political processes or Delphi methods), and sometimes that is necessary if the benefits and/or costs cannot be accurately estimated. However, accurate economic benefit-cost analysis has the advantage of improving our confidence that we have arrived at the best possible decision.

While benefit-cost analyses assess social choices in a very real, important sense, they do so only in special, confined ways. Certain social "values" or considerations are not addressed in benefit-cost analyses. Those considerations are (1) social equity, (2) human rights or other ethical judgements and often (3) economic impacts. Social equity in the economic sense is usually thought of as the distribution of wealth among members of our society. The benefits and costs of projects are measured in terms of willingness to pay or to accept compensation, and these depend upon the distribution of wealth, so all benefit-cost analyses depend to some extent on income distribution. The results might differ if income were distributed differently. In fact, whether or not gainers actually pay losers will have some effect on income distribution so even this could affect the results of a benefit-cost analysis. In addition, if the existing distribution of income in society were considered "unfair," then any benefit-cost analysis might also be considered "unfair." These considerations are ignored in benefit-cost analysis.

Human rights and other ethical judgements are usually also ignored in benefit-cost analyses. Obviously human values are based upon human biases and ethics, but benefit-cost analyses do not attempt to distinguish "good" ethics from "bad" ethics. Political judgements may do so, however, and those judgements may influence the results of benefit-cost analyses. This is also true with regard to social equity.

"Economic impacts," to economists, are measures of the transfer of income and/or employment from one region to another or from one sector of the economy to another as a result of some change in the economy. One so often hears about the dollars spent by recreationists at motels, restaurants and gas stations; or that commercial fisheries not only employ the fishers themselves but also the processors and perhaps local restaurant personnel. These impacts are usually not relevant in benefit-cost analyses because they are not measures of benefits or costs. They are instead measures of the location of economic activity. The only aspects of economic impacts that should be included in benefit-cost analyses are: (1) the positive or negative values of alleviating or causing unemployment of capital or labor, and (2) the value of progress toward or away from any social goal of transferring income and employment from one region or economic sector to another. Communities and regions are often concerned with economic impacts because they greatly influence local growth patterns and community integrity. These considerations are more likely to form part of a political judgement than a benefit-cost analysis because economists have great difficulty measuring the values represented by such concerns.

Finally, we should point out that the "macro" judgements of any society are usually considered beyond the useful scope of benefit-cost analysis. For example, the decision to open western North America to homesteading, and the decision to put a man on the moon by 1970 both represent deliberate political choices resulting in major directional changes for society. These kinds of decisions lead to changes which are largely uncertain or even totally unanticipated at the outset. Instead there is really only a strong conviction that the ensuing benefits will more than offset the overall costs of attaining them. A traditional, detailed benefit-cost analysis is neither possible nor would it increase public confidence in the merits of this kind of decision. Any major redirection of society or its economy will in itself change the values we rely upon to estimate dollar benefits and costs, thereby reducing the reliability of the analysis. This is an important point since the ecosystem rehabilitation measures proposed in this study, when taken together, constitute a major directional change akin to those noted above.

Benefit-cost analyses are more helpful in assessing particular measures which may be contemplated for a rehabilitation strategy for some particular ecosystem. In this context at least some of the direct and indirect benefits and costs can be identified, as for example, when deciding whether or how to redesign water intake structures, enforce more stringent waste treatment standards, or restrict fishing activity. Even here two kinds of difficulties are encountered. One is that a number of benefits and costs occur outside of the market price system. Recreational and aesthetic benefits for example are difficult and expensive to measure.

Another difficulty which may be particularly significant for ecosystem rehabilitation is that benefit-cost analyses cannot really deal with absolute scarcity or finiteness. Bishop (1978) has argued, for example, that the economic feasibility of endangered species maintenance cannot be known because extinction is irreversible and has very uncertain consequences. Here decision criteria other than economic feasibility are called for. This would certainly apply to rehabilitation efforts that influence whether a species will survive or not.

A closely related point has to do with intergenerational economics. Rehabilitation efforts are to some extent envisioned as major steps toward changing the set of natural resources that our descendants inherit. More and more economists are questioning whether present values of benefits and costs (i.e., discounting future benefits and costs) adequately reflect society's values in such cases. Space will not permit going into detail. It will have to suffice to say that society might quite rationally choose to do economically "infeasible" things for the sake of future generations, particularly when dealing with potentially irreversible damage to natural resources.

Having said all this, however, it is still true that conventional economic values will have some bearing on whether rehabilitation activities will receive public support and funding. We can summarize some relevant economic information that is now available, beginning with the cost side.

Rehabilitation costs

We have not attempted an exhaustive search of the literature. Rather, we hope to place rehabilitation in an economic perspective by assessing the economic "ballpark": the order of magnitude of the kind of expenditures which come into play when we look at rehabilitation in the Great Lakes (Table 4.1).

It is clear, first of all, that the United States and Canada have already committed major resources to rehabilitation. Consider point source pollution. In all of the United States, for example, something in the neighborhood of $10 billion were expected to be invested in industrial water pollution control equipment to meet standards by 1976, with annual replacement, interest and operating costs running in the neighborhood of $1.7 billion (U.S. Environmental Protection Agency 1973). Other estimates run as high as $25 billion total investment (Savage et al. 1974). Economists have generally considered the $10 billion to $25 billion figures to be upper bounds, since new technologies and previously unrecognized methods of avoiding or reducing discharges are likely to be discovered and implemented. On the other hand, it must be remembered that such estimates are probably in 1970 or 1972 dollars which have not been adjusted for inflation.

Much of this has been spent in the Great Lakes watershed. In EPA Region V, covering all of Illinois, Indiana, Michigan, Minnesota, Ohio,

Table 4.1. The economic “ballpark” for Great Lakes rehabilitation.

1. Rehabilitation costs
   a. Point-source controls-about $1 billion/year in U.S. for industrial and municipal sources.
   b. Non-point source controls
      - agriculture-no over-ah estimates, but up to a point could yield benefits to farmers;
      - urban-about $0.5 to $1 billion/year for the U.S. Great Lakes region.
   c. Micro-contaminants
      - PCB ban may add about $110 million annually to costs over the entire U.S.;
      - costs for other contaminants uncertain.
   d. Fisheries management in Great Lakes waters
      - U.S. federal plus states expenditures may be about $21 million annually for Great Lakes waters;
      - Canadian federal and provincial expenditures of about $20 million annually.
   e. Impact of rehabilitation measures on energy, industry and navigation-no firm estimates.
   f. Wetlands, and other habitat rehabilitation costs unknown.
2. Rehabilitation benefits
   a. Sports fishing
      - total net benefits may be in order of $525 million annually for entire Great Lakes.
   b. Commercial fisheries
      - dockside values of about $25 million annually (for entire Great Lakes) plus “consumer surplus” value estimates which yield total gross benefits of $30 million, and net benefits of $12 million annually.
   c. Other recreation benefits not quantified
   d. Reduced costs for domestic water supplies not quantified
   e. “Existence” values and “option demand” recognized but not quantified.

and Wisconsin, total capital costs to meet 1977 effluent standards was expected to be $3 billion with total annual cost including replacement, interest and operation of around $768 million (U.S. Environmental Protection Agency 1973). One estimate for the Great Lakes (U.S. only) was $3.7 billion for industrial and municipal waste treatment for the years 1967-73 including capital investment and operation and maintenance. Thus the annual cost of controlling municipal and industrial pollution during that period for the Great Lakes alone is about $360 million in 1968 dollars (Hennigan 1969). Given more stringent standards and inflation, the U.S. is probably spending in the neighborhood of $1 billion or more per year on reducing industrial and municipal point-source pollution of the Great Lakes.

While billions of dollars worth of resources can never be dismissed as insignificant, it is very important to look at these costs in perspective. The U.S. Environmental Protection Agency (1972) has shown that reductions of point source water pollution in the United States through 1976 should add one percent or less to costs of producing all major industrial products. The United States as a whole is spending less than one percent of its GNP on reductions in water pollution from industrial and municipal sources (Pearce 1976). While there has been some tendency among economists to portray the pollution problems as involving major trade-offs between economic growth and environmental improvements, these figures do not support such a view. On the contrary, the costs of major steps toward cleaning Up water appear surprisingly small in relative terms.

Given that past improvements have not caused major cost increases in most products, the question arises whether additional reductions in pollution could be accomplished at modest costs. It is clear that costs rise at an increasing rate as the amount of pollutant is reduced. For example 30 percent of the BOD wastes from meat processing can be removed for about $0.06 per pound of waste, 90 percent can be removed for $0.60 per pound of waste, and 95 percent can be removed only at a cost of about $0.90 per pound (Peskin and Seskin 1975). Such figures indicate that as the United States moves toward "best available technologies" by 1983 and possible additional reductions in pollution loads thereafter, costs are likely to rise exponentially. On the other hand, we are likely to overestimate costs such as those relating to meat processing because new pollution abatement techniques may be developed.

Concerning control of non-point sources of pollution some encouraging results have been forthcoming from recent agricultural economic studies. The most recent such study, by Forster and Becker (1978) considered the changes in net farm income for Honey Creek Watershed in the Lake Erie Basin which would occur if measures to reduce soil erosion were implemented. That study showed phosphorus and soil losses could be reduced 50 percent with a slight increase in the profits of area farmers. Reductions in erosion rates and phosphorus losses beyond the 50 percent level caused area farm profits to decrease at an increasing rate. Consideration of this conclusion and other related studies (Swanson 1978; Taylor and Frohberg 1977; Wade and Heady 1977; Walker 1977; and White 1978) indicate that the extent of reduced profits to farmers from erosion control vary considerably depending on soil type and the farming operations, but that there are opportunities to reduce agricultural water pollution by substantial amounts at low costs in many locales.

Urban non-point pollution control may be more expensive. Work by Skimin, Powers, and Jaricki (1978) indicates that costs for municipal non-point source pollution control in the United States Great Lakes basin could exceed agricultural costs by a factor of two, three or more. Still, the most stringent plan discussed in their report involved costs of $972.4 million annually, and several less extreme alternative strategies have estimated costs of less than half a billion dollars annually. Considerable headway toward controlling both point and non-point source pollution of the Great Lakes could apparently be made at an annual cost of less than $2 billion.

On the microcontaminant side of the pollution question, there are few data on the potential costs of avoiding the introduction of harmful microcontaminants into the Great Lakes. The only such study we have found relates to the costs of the ban on PCBs which is currently being implemented in the United States under the Toxic Substances Control Act. MacArthur and Nagy (1976) estimated that such a ban would result in a considerable initial cost and an additional annual cost of about $110 million. This figure applies for the entire United States, not just the Great Lakes region.

Major commitments have also already been made to rehabilitate and enhance Great Lakes fisheries. The GLBC/Fish Work Group (1975), in the only attempt we found, assessed the costs of these efforts. Their estimates were hampered by the fact that expenditures for the Great Lakes are sometimes not segregated from expenditures on inland fisheries. Furthermore, the costs reported were for the late 60's and early 70's, before the salmonid fisheries were in full-swing. Figures for enforcement, stocking, sea lamprey control, research, and related activities as reported in that study add up to about $5.6 million per year for the United States only. A more recent study (Comptroller General of the United States 1977) found that the U.S. Federal Government spent $7.5 million during fiscal year 1975 on programs related to Great Lakes fisheries. This same study estimated that the 2.8 million anglers and commercial fishermen who fished the Great Lakes spent $11.3 million for fishing licenses during 1975. Since license fees are the normal source of revenues for state level fish stocking and management efforts, and since these license fees would have been divided between inland and Great Lakes programs, a rough estimate of combined United States federal and state expenditure on fishery related rehabilitation and enhancement would be about $2 I million to $22 million per year in 1979 (Talhelm et al. 1979). Canadian federal and provincial expenditures are about $20 million in 1979 for similar purposes (Talhelm et al. 1979). To this must be added many millions of dollars spent by sport and commercial fishers. Recreational anglers in Michigan alone are spending around $100 million per year on equipment, travel and otheractivities related to Great Lakes fishing. Total angler expenditures for all Great Lakes sport fishing appear to be about $440 million (Talhelm et al. 1979). The economic impacts of these expenditures may be about $1 billion annually. The economic impact of commercial fishing and associated industries is about $160 million annually (Talhelm et al. 1979).

Additional rehabilitation efforts may conflict with other major economic activities. Two examples are commercial navigation and electric power generation. Commercial navigation is certainly one of the most important economic uses of the Great Lakes. The U.S. Army Corps of Engineers (1979) estimated that the lakes and associated waterways (United States and Canada combined) are carrying 100 billion-ton miles of cargo per year. Some idea of the net benefits associated with this activity can be gained by examining the Corps' economic analysis of the proposal to extend winter navigation on the Great Lakes. The preferred plan in the judgement of the Corps (U.S. Army Corps of Engineers 1979) claimed net benefits of $236 million annually just for winter navigation. While these figures have not gone undisputed, they still suggest that the total net benefits for all navigational activities must apparently be in hundreds of millions if not billions of dollars annually.

Rehabilitation strategies for the Great Lakes are not likely to conflict seriously with commercial navigation. At most they might raise issues concerning minor changes such as rerouting shipping around important fish habitat or phasing out or relocating minor port facilities.

Similar thoughts are applicable to power generation. The issues here center around cooling water and associated effects. The choices under current technology are between once-through cooling where water is pumped from the source, circulated through the condenser, and dumped directly back into the water source; and closed-cycle cooling where cooling towers or ponds are used to cool the water so that it can be recycled. It is generally believed that once-through cooling has the economic advantage since expensive cooling towers and other facilities need not be constructed, operated, and maintained, and since once-through cooling requires less fuel due to greater engineering efficiencies. Once-through cooling does require large volumes of water, and in the Great Lakes region most large power plants with once-through cooling are located on the Great Lakes.

In Wisconsin, at least, the economic advantages of once-through cooling have been erased by current environmental requirements for intake and discharge equipment to reduce thermal pollution and damage to aquatic organisms (Bishop and Vogel 1977). These requirements have made inland sites with closed cycle cooling competitive with Great Lakes sites. Unfortunately from the point of view of rehabilitation efforts, the economic justification for these requirements is questionable under present conditions. For example, one study (Westinghouse Electrical Corporation 1971) estimated that fitting Wisconsin's Kewaunee Nuclear Plant with cooling towers would result in reduced fish kills of 10,310 pounds per year but would increase fuel costs by $600,000 per year, or about $60 per pound of fish counting only fuel costs and not construction, operation, or maintenance of the cooling system itself. Bishop and Vogel estimate that the additional cost of fuel for a single 1800 MW nuclear plant using closed system cooling would be $2.9 million to $4.3 million per year. If capital, operation, and maintenance costs were added in, the economic damage to fisheries and related resources would have to be quite large to justify steering clear of traditional once-through cooling techniques.

Future relationships between thermal discharge and fisheries are uncertain. Demand projections for electric power have been revised downward throughout the basin, but there will still probably be a number of additional power plants on the Great Lakes by the year 2000. The effects of isolated power plants are likely to be local and can be minimized through careful design and location. However, some scientists warn that sufficient thermal discharge at the wrong locations and times may significantly disrupt fish migrations, particularly those along the shoreline and those from offshore to inshore. Thermal discharge may also destroy fish eggs and larval fish during short, critical exposure periods.

To conclude this section on costs, let us look at some costs of rehabilitation about which very little is known. These, perhaps, can be taken as topics for future research. First, rehabilitation measures must to some considerable extent in a number of areas incorporate tight restrictions to minimize damage to critical fish and wildlife habitats, including wetlands and many inshore areas. In addition to being convenient dumping grounds for pollutants, wetland areas are often viewed as attractive places to "create" new dry land through filling. Particularly given the aesthetic attractiveness of developments at the waters edge such "new" lands are likely to be worth a great deal near urban areas. On the other hand, new lands may reduce the value of property on the previous shoreline. What would be the social cost of protecting wetlands and near-shore areas?

Secondly, a great deal of fish and wildlife habitat has been degraded through siltation, deposition of dredged material, filing, and other activities, both in the lakes and bays themselves, and in tributary rivers and creeks. More attention should be given to options for enhancing the productivity of these ecosystems through artificial reefs and other measures. What would such measures cost?

Fishery-related benefits

It is clear first of all that rehabilitating Great Lakes salmonid and warm water fisheries through sea lamprey control, stocking, and other management measures has produced large amounts of recreational benefits. Preliminary results of research by Talhelm (1979) indicate that net recreational benefits to anglers fishing for Michigan's Great Lakes fish are about $21 per angler, or about $210 million annually assuming 10 million angler days (Talhelm et al. 1979). This value does not include actual expenditures (cited above in the cost section) of **$100** million annually. Since there appear to be roughly 25 million angler days per year for Great Lakes fish throughout the region, total net benefits may be in the neighborhood of $525 million per year (Talhelm et al. 1979). These figures are rough approximations and should be refined through further research. Better estimates for Michigan and Wisconsin should become available in 1979.

It is also clear that expansion of sport fish populations would generate substantial benefits. For example, a recent survey of Wisconsin Lake Michigan sports anglers showed that they would be willing to pay an average of $13 per year to catch one additional fish per day. Since the average **angler fishes Lake Michigan four days per year, this averages out** to $3.25 per fish. This particular method of valuing resources is probably inaccurate (Bishop 1979) and probably yields low estimates compared with what people would actually be willing to pay. Thus, $3.25 appears to be the minimum average value of each additional fish. If stocking costs of $1 per fish caught are correct as estimated by the Wisconsin Department of Natural Resources, there may be attractive investment opportunities involving increases in sport fishing success rates. Further research on this question in Michigan and Wisconsin is also expected to become available in 1979.

In considering sport fishing rehabilitation investments, it is important to bear in mind the importance of exotic species in the sports fisheries. This is another point that was reinforced by the Wisconsin angler survey. When asked to rank the desirability of various salmonids, 31 percent ranked chinook salmon (an exotic) as most preferred. Second was rainbow trout (an exotic) at 22 percent. Third was brown trout (exotic) at 18 percent. Lake trout (native) and coho salmon (an exotic) were nearly tied for fourth with 14 and 13 percent of the anglers respectively ranking them as their most preferred species. Restoration programs designed to replace exotic salmon and trout with native species may run into substantial conflicts. Smelt may have become another important recreational exotic but this has not been researched.

The gross benefits to society from commercial fishing are much smaller. The 1975 dockside values of the U.S. and Canadian catches were $9.1 million and $9.6 million respectively (Comptroller General of the United State 1977). The 1979 dockside value should be about $25 million. Although research on the demand for Great Lakes fish has not yet progressed enough to accurately estimate gross and net consumer willingness to pay, they can be roughly estimated as demonstrated by a recent study of the supply and demand of whitefish (Ghanbari 1977). In that Michigan study, the ratio of net consumer willingness to pay (consumer surplus) to dockside value was 0.22, indicating that consumers would be willing to pay up to 22% more than they now do, rather than not have whitefish. This assumes that other fish would still be available at present prices. In addition, producers are potentially willing to pay greater license fees for the privilege of fishing, so the overall ratio of net resource value to dockside value is around 0.5. Applying these ratios to the entire Great Lakes yields gross benefits from Canadian and U.S. commercial fishing of about $23 million per year and net benefits of about $9.3 million per year in 1975. This would be considered a lower bound because the ratio used does not account for interrelationships in the demand curves for different Great Lakes species. The actual figure for 1979 gross benefits would probably be around $30 million and net benefits around $12 million.

The small relative size of the commercial fishing industry should not be grounds for disregarding the potential benefits to the industry from rehabilitation efforts. If such efforts enhance the productivity of higher valued species, the economic rewards could still be substantial. Except for whitefish, the traditional high valued species like lake trout, chubs, yellow perch, and lake herring are at small fractions of their former levels of commercial production for a variety of reasons. At current prices and production costs levels, enlarged fisheries for these species could be economically very attractive.

Nor should the relatively small benefits associated with commercial fishing be interpreted as a reason for eliminating commercial fishing in favor of recreational fishing. **Actually the economics of this issue are** quite complex (Bishop and Samples 1978; Talhelm 1979) and have not yet been adequately studied by economists in the Great Lakes region or elsewhere. It is interesting to note that the Wisconsin Lake Michigan anglers survey showed that while they do see commercial fishermen as competitive users of the resource, 70 percent agree that commercial fishermen provide a service by making fresh fish available to Wisconsin residents. Adequate assessments of the economic values and trade-offs between recreational and commercial fishing must await further research.

Other benefits

About other potential benefits of rehabilitation we have substantially less knowledge and must speak in very general terms. It is clear that the Great Lakes region has a large and growing population. Great Lakes Basin Framework Study projections show a population of 33.6 million people on the U.S. side alone by 1980 and 45.3 million people in 2000. It is true that these people and their employers will generate large amounts of potential pollutants that will have to be dealt with, but they also demand outdoor recreation, clear drinking water, a pleasant environment, and other beneficial outputs of rehabilitation.

Boating is a major recreational use of the Great Lakes. The Great Lakes Basin Framework Study estimated annual boating use on the U.S. side alone at more than 7 million recreation days. Swimming, picnicing, hiking, photography, and other such activities occur all along the lakeshore but total use has not been estimated. All of these groups are likely to benefit from rehabilitation and enhancement of the living resources and waters of the Great Lakes, particularly since some of the most damaged and polluted areas are near major cities. These benefits have not yet been estimated, but probably are in the hundreds of millions of dollars or more annually.

Lakeshore property sells at a premium. Economists have attempted to look at how property values relate to environmental quality with mixed results, but nothing yet exists to help us understand how rehabilitation efforts on the Great Lakes might influence property values.

Another benefit of rehabilitation may be reduced costs for domestic water. We take domestic water for granted, but actually it costs us quite a bit. One report estimates that the State of Michigan alone will have spent more than $250 million between 1970-1980 to develop new domestic water resources including non-Great Lakes sources (GLBC/Water Supply Work Group 1975). Disrupted ecosystems can create serious water supply problems. For example, the Lake Michigan alewife die-offs in the 1960's nearly cut off water supplies in some areas when they clogged water intake systems.

Finally, perhaps the greatest values of ecosystem rehabilitation derive from the fact that people strongly value "healthy," productive Great Lakes ecosystems. They feel better off, perhaps more secure, in the knowledge that healthy Great Lakes exist, and will be available in case they or their offspring wish to use them. The public appears willing to pay for many rehabilitation efforts for these reasons alone. Economists refer to these values as "existence" values and "option demand," and find that estimating them is very difficult, but theoretically possible. Judging from public and political support for rehabilitation efforts, these values may be in the billions of dollars annually.

Summarizing economic feasibility

It is not possible to summarize the economic feasibility of rehabilitating the Great Lakes in one overall benefit-cost statement. There are far too many alternative forms of rehabilitation, each having to be tailored to particular situations and each implying a different set of trade-offs. Specific sets of rehabilitative measures are best evaluated with reference to particular locations, and we have given some examples in this chapter. However, examining the benefits and costs of a wide range of alternatives may help us visualize the economic feasibility of rehabilitation as summarized in Table 4.2

One extreme objective for rehabilitation would be complete restoration of Great Lakes ecosystems to some form similar to a previous "ideal'‘-say, that of 100 years ago. Exotic fishes and other organisms would be eliminated and native ones restored; wetlands, harbors, channels and similar locations would be restored; most fishing would be prohibited so fish populations could contain large numbers of old, larger-sized fish; man-caused pollution would be almost completely eliminated; and other similar actions would be taken. It seems obvious from our previous discussion that the costs would be very great, in some cases the situations are even beyond present-day technology. While the benefits may also be great, they seem nowhere near as great as the costs. Evidence of this comes from the fact that practically no one who is contemplating various degrees of restoration-including biologists, legislators and other elected officials, engineers, chemists and interested

Table 4.2. Some conclusions about economic aspects or rehabilitation.

1. A great deal is not known about the benefits and costs of rehabilitation.
2. Some degree of rehabilitation ***is*** highly beneficial overall.
3. Benefit-cost analysis may be best used to assess incremental decisions on case by case basis.
4. More needs to be known about public values ***implicitly*** placed on:
   a. keeping options for the future open;
   b. preserving endangered species and threatened ecosystems;
   c. equity in the allocation of Great Lakes resources;
   d. "existence values," i.e. the value placed on knowing that the Great Lakes are ecologically "healthy" and pleasant to be around.

public-seriously considers complete restoration to be in the public's best interest. It is incompatible with the public's interests in utilizing Great Lakes resources.

The opposite extreme is degradation: writing off the Great Lakes as places to fish, swim, boat or obtain drinking water, or as pleasant places to live near or even view and instead using them as a place to dump wastes, to be filled or dredged for industrial use, and for other compatible uses such as shipping, mining and oil recovery. The benefits would be great, particularly the billions of dollars that would be saved in reduced pollution control and prevention costs, reduced toxic substance disposal costs, and reduced recreation management costs. However, the costs of degradation would be even greater than these benefits. Perhaps the greatest cost would be the loss in benefits the public derives from knowing that the Great Lakes are ecologically "healthy" and pleasant to be around, and will continue to be so in the future. Evidence of this comes from the support demonstrated by the public for pollution control. Political action is popular, and surveys show that the public favors spending tax money to control pollution. Therefore the public benefits must be considerably greater than the billions of dollars in costs. Serious degradation appears incompatible with the public's interests.

Neither extreme is acceptable, so the optimal solution is somewhere between. It is not necessary to quantify the benefits and costs of the extremes any more precisely than this to be confident of that fact. Our mechanisms for sampling public opinion provide ample assurance. However, there are many smaller decisions between the extremes for which the evidence is not so obvious. In these cases a more in-depth benefit-cost analysis can help us understand public values and be more confident in public decision making. The benefits and costs cited earlier generally seem to support most current rehabilitative efforts in the Great Lakes, but specific incremental decisions should be analyzed on a case by case basis. In addition, as we found in the Green Bay and Bay of Quinte examples (see Chapter 6), Delphi and other methods can often be used to assess benefits and costs in a very general way, perhaps narrowing the range of choices that need detailed benefit-cost analyses. So few economic analyses have been completed so far that Delphi and similar techniques, and political processes, may provide the most accurate assessments of many choices for many years into the future.

The Organization for Economic Cooperation and Development has drawn attention to a number of economic benefits associated with environmental protection policies adopted by western industrialized countries (OECD 1979). At the level of individual enter-prizes, the need to respond to higher pollution control standards can be the incentive to seek greater efficiencies in the overall use of energy, raw materials and water through introducing low waste technologies and other production process modifications. There are a number of instances where these kind of adjustments have resulted in higher profits as well as lower pollution (Royston 1979).

5. INSTITUTIONAL ARRANGEMENTS FOR REHABILITATION

Can the ecosystem rehabilitation strategies outlined in earlier chapters be easily carried out through the existing institutional arrangements? If so, how so and if not, what changes have to be made? This chapter first draws attention to some of the salient features of the standing structure of institutional arrangements which serve to direct, restrain or otherwise influence resource uses of the Great Lakes ecosystem. It then outlines an approach to mobilizing selected components of this structure to pursue ecological rehabilitation strategies in designated areas within the Great Lakes basin.

The term "institutional arrangements" refers to the division and coordination of an array of functions and activities among a number of organizations each otherwise having its own objectives, responsibilities, interests and expertise. Collectively, this constitutes an inter-organizational system which can be defined by component organizations and groups ("actors" in the sociological sense) and the transactions or exchanges among them. It is also an identifiable system for public decisions and actions which can in principle be analyzed, evaluated and held socially accountable.

Present structures

Given the sheer size of the Great Lakes basin, shared by two countries and having a total population of some 37 million people, it is no surprize to find an exceedingly complex system of institutional arrangements which bear on various aspects of the planning and management for water, shoreline and associated land uses. The two constitutional federalisms alone provide for elaborate structures for governance. In addition, with the vigorous development of corporate enterprise in this industrial heartland of North America, and the innumerable other groups organized around particular interests, the over-all institutional complexity may well defy comprehension. The basic framework for the structure of governance over the Great Lakes basin is of course given by the international boundary, combined with the constitutional division of jurisdictions in each country. This results in the 11 basic components as represented by the two federal governments, eight states and one province. Within each of the components there is a secondary structure defined by various statutes which have over time allocated the functional responsibilities. Constitutional documents help reinforce this structure, especially in the United States. The framework is summarized in Table 5.1.

For Great Lakes matters, there have been various provisions for intergovernmental cooperation among jurisdictions. Collectively then, this basic structure combined with inter-governmental arrangements constitutes the policy framework through which governmental responsibilities for the Great Lakes ecosystem are carried out. Table 5.2 identifies

Table 5. I. Basic policy framework for the Great Lakes

CANADA	Levels of Government	UNITED STATES
Federal		**Federal**
Federal-provincial coordination by intergovernmental agreements e.g. "Environmental Accord" "SPOF," etc.	Binational coordination IJC and GLFC	Federal-state coordination by statutory commission (i.e., GLBC), and special programs (e.g., CZM)
Provincial		**State**
		Inter-state coordination by inter-state compact i.e. GLC
Special purpose governing units. i.e. Conservation authorities		Special purpose governing units. e.g. Regional planning commissions "208" planning units Soil conservation districts
Municipal		**Municipal**
Metropolitan areas, counties (regions), townships		Metropolitan areas, counties, townships

Table 5.2. Main components of the basic policy framework governing the management and uses of the Great Lakes ecosystem.

A. Canada-United States binational arrangements
  1. Treaty between the United States and Great Britain Relating to Boundary Waters and Questions Arising Between the United States and Canada (Boundary Waters Treaty), 1909.
     International Joint Commission, 1912
     Great Lakes Water Quality Agreement, 1972
     Great Lakes Water Quality Agreement, 1978
  2. Treaty of Niagara Falls, 1950
  3. Convention on Great Lakes Fisheries, 1955
B. Inter-governmental arrangements within each country
  1. United States
     Great Lakes Basin Compact, 1955, PL 90-419
       Great Lakes Commission, 1955
     Water Resources Planning Act, 1965, PL 89-80
       Great Lakes Basin Commission, 1969
  2. Canada (Federal-Ontario)
     Canada-Ontario Agreement on Great Lakes Water Quality, 1971
     Canada-Ontario Environmental Accord, 1976
     Canada-Ontario Agricultural and Rural Development Agreement, 1970
     Strategic Plan for Ontario Fisheries, 1978
     Canada-Ontario Rideau-Trent-Severn Agreement, 1975
     Canada-Ontario Great Lakes Shore Damage Survey, 1973
C. Federal legislation (most recent first)
  I. United States
     Clean Water Act, 1977, PL 95-217
     Toxic Substances Control Act, 1976, PL 94-469
     Resource Conservation and Recovery Act, 1976, PL 94-580
     Safewater Drinking Act, 1974, PL 92-523
     Endangered Species Act, 1973, PL 93-205
     Rural Environmental Conservation Act, 1973, PL 93-125
     Coastal Zone Management Act, 1972, PL 92-583
     Environmental Pesticide Control Act, 1972
     Water Pollution Control Act Amendments, 1972, PL 92-500
     Water Quality Improvement Act, 1970
     Clean Air Act Amendments, 1970, PL 91-604
     Water Bank Act, 1970, PL 91-559
     Fish Restoration Amendments Act, 1970, PL 91-503
     National Environmental Policy Act, 1969, PL 91-190
     Clean Water Restoration Act, 1966
     Anadromous Fish Conservation Act, 1965, PL 89-304
     Federal Water Quality Act, 1965
     Commercial Fisheries Research and Development Act, 1964, PL 88-309
     Water Pollution Central Act Amendments, 1961
     Federal Water Pollution Control Act, 1956
     Watershed Protection and Flood Prevention Act, 1954
  2. Canada
     Environmental Contaminants Act S.C. 1974-75, c.72
     Federal environmental assessment and review process. Cabinet Directive, December 20, 1973
     Clean Air Act S.C. 1971, c.47
     Canada Water Act SC. 1970, c.52
     Fisheries Act R.S.C. 1970, c.F-14
     Canada Shipping Act R.S.C. 1970, c.S-9
     Navigable Waters Protection Act R.S.C. 1970, c.N-19

Table 5. 2. (Continued)

National Housing Act R.S.C. 1970, c.N-10
Regional Development Incentives Act R.S.C. 1970, c.R-3
Pest Control Products Act R.S.C. 1970, c.P-10
Atomic Energy Control Act R.S.C. 1970, c.A-19
Harbour Commissions Act R.S.C. 1970, c.H-1
D. State-Provincial
A number of relevant statutes could be listed here. It is important to note that in both Canada and the U.S., federal legislation often establishes policy guidance and may provide certain funding to assist in policy implementation. In the U.S., greater reliance is placed upon cooperative programs jointly funded between federal and state agencies for resource management.

the main elements of this framework in terms of binational treaties and conventions, major intergovernmental agreements and other comparable arrangements, and major federal legislation. Provincial and state laws are also vital complements to this, as are municipal governments and various multi-county arrangements established for land and water planning in the Great Lakes states and Ontario.

Within this basic policy framework there are a large number of governmental units all having some responsibilities which bear on water, shoreline and associated land uses. Many of these units would also eventually be involved in implementing strategies for ecosystem rehabilitation. The resulting complex itself can be viewed as a kind of "organizational ecosystem," one which is a long way from being fully "mapped." There have however, been a few preliminary and overlapping inventories made for different purposes, and these reveal the order of magnitude of the governmental components alone (Table 5.3).

Although there are few if any detailed studies concerning the actual functioning of the basic policy framework or the "organizational ecosystem" within it in terms of effective handling of Great Lakes problems, there has nevertheless been some thought given to desirable changes which should be considered. Two of the more elaborate proposals were developed largely independently in the early 1970's, but they drew on much the same body of writings about water resources management and arrived at similar conclusions.

One was developed through a literature review and consultation process by the Canada-United States University Seminar in 1971-1972. It noted the inherent interrelationships among various water and associated land uses and among various resource management problems in the Great Lakes. The scope of existing binational arrangements fell far short of what would be needed to keep abreast of such problems, consult on possible joint solutions, and agree to implement appropriate measures within each country. The desirability of having a two-tiered arrangement was proposed. The first tier would be a basin-wide binational policy body which would have a monitoring and surveillance function to gather the necessary "intelligence" information on different problems and on what

Table 5.3. Partial inventories of governmental organizations dealing with various aspects of Great Lakes resources and environmental management.

Areas of responsibility: and jurisdictions	Estimated number of government organizations	Source
Water quality, Lake Erie, U.S.: federal, state, local government agencies	132	Kent State University 1975
Control of non-point pollution from land use, U.S.: federal, state agencies	a	IJC/PLUARG 1977a
Shoreline jurisdiction, U.S. and Canada: state-provincial, regional and local government units	650+	Bulkley and Mathews 1974
Fisheries and fishing industry, Ontario: federal, provincial	32	SPOF 1975 (Loftus et al. 1978)
Fisheries, U.S.: state, federal	25+	
Water, shoreline and land use, Canadian Great Lakes basin: federal, provincial, regional agencies	a	Marshall, Spaling and Wismer 1977
Control of non-point pollution from land use, Canada: federal, provincial, regional agencies	a	IJC/PLUARG 1977b

[a]Total number not tabulated

was being done about them in the jurisdictions around the Lakes. It would also be empowered to sponsor informal consultations as a kind of mediator on issues requiring a joint binational response. The other tier would develop through strengthened cooperation at the sub-basin level and for special problem areas. It was to be encouraged by clear authorization given to "opposite number" government agencies to collaborate with one another "in a transborder manner" for a number of management questions. Suitable strengthening of the IJC was advocated to bring this about (Canada-United States University Seminar 1973; U.S. House of Representatives 1973; Canada Senate 1975).

The other set of proposals was developed by Craine (1972) for the Great Lakes Basin Commision. They also envisaged an essentially two-tiered set of arrangements for resource planning and management in the United States portion of the Great Lakes basin, subject to whatever binational agreements may be reached with Canada. The upper tier would be a basin-wide policy agency having two major functions. The first would be "anticipatory planning" to discern needs for policy determinations and to develop policy guidelines. The second, would be "reactive conflict resolution" for which the agency would have powers to adjudicate conflicts and out of which it would gain the experience needed to evolve policy. The lower tier would take the form of special agencies devoted to "geographic integration" in sub-basins or regions of the Great

Lakes where the problems encountered in such areas would seem to require this more concerted approach to management. These agencies would exercise specific planning functions under broad policy guidelines provided by the basin policy agency, and they would exercise selected resource management functions. Thus, they would become special area management organizations linked clearly and carefully into a network of other existing organizations carrying out some of the necessary functions. While these proposals have not been acted upon, Nickel states that the rationale of the approach remains of considerable interest to the GLBC. [1]

Modifications of the basic policy framework for the Canadian portion of Great Lakes basin have been proposed by MacLaren (1976, 1977) who called for the establishment of a federal-provincial commission analogous to the U.S. Great Lakes Basin Commission. This Great Lakes Resources Commission would sustain Canadian participation in bilateral agreements with the United States under the surveillance of the International Joint Commission. Rather similar ideas have been discussed at other meetings which have dealt with the question of the adequacy of the present basic policy framework for joint cooperation between Canada and the United States on Great Lakes issues (Can.-U.S. Univ. Sem. 1973; IJC/GLSAB 1979).

Although no changes have been made to date by either country along the lines of these various proposals and suggestions, the latter do however help to stress two essential points which pertain to the design of effective ecosystem rehabilitation strategies. One is the need to differentiate between those components of the strategy which need to be tailored to the specific situation posed by particular problem areas such as bays or harbors, and components which can only be carried out effectively on a basin-wide basis under agreed policy. The other is the need to review from time to time the sufficiency and compatibility of the institutional arrangements of both countries for sustaining effective rehabilitation strategies that combine basin-wide with specific problem area components. In addition, these arrangements would have to facilitate measures to maintain rehabilitated conditions. This in turn may require more intensive resource management activities at the problem area level as well as improved anticipatory capabilities to ward off new or recurring stresses which threaten rehabilitated systems.

Some of the necessary components of ecosystem rehabilitation strategies are already being carried out at the basin-wide level. Under the 1972 and 1978 Great Lakes Water Quality Agreements, stresses placed on the Great Lakes ecosystem from source pollutants are being reduced by more stringent waste treatment measures. In the Bay of Quinte this has already resulted in some recovery of the aquatic ecosystem. The recovery commenced within a year of marked reductions in point source phosphorus discharges. Under the 1978 Agreement, the two countries are

1 Paul E. Nickel, Planning Director, GLBC 1979: personal communication.

committed to more stringent measures for dealing with toxics and other hazardous materials, and to remedial measures for reducing non-point source pollution arising from various land use activities. In addition, under the 1955 Convention on Great Lakes Fisheries, intensive measures to control sea lampreys and restore the lake trout fishery are being maintained under the aegis of the GLFC. This Commission informally coordinates the enhancement of sports fisheries in the lakes, especially the introduction of large exotics.

Nevertheless, as indicated previously, additional more localized measures have to be considered in developing a comprehensive ecosystem rehabilitation strategy for areas like Green Bay and the Bay of Quinte. This means that while the basin-wide efforts overseen by the two binational commissions are necessary and should certainly continue, attention must now be directed to designated areas within the lakes to devise a complementary set of additional measures. Once these get worked out and tried out they should provide a clearer indication of what additional measures or changes will be needed at the basin-wide level to complete and support sub-basin strategies for the various designated areas.

Strategies for designated areas

The designated areas requiring attention could be either areas so degraded that special rehabilitation measures are needed, or they may be areas of known environmental sensitivity where special protective measures have to be devised to maintain their existing ecosystem qualities. Examples of the former would be semi-enclosed bays or harbors ringed by industrialized shorelines and, of the latter, known spawning or overwintering sites for important fish stocks, and some nesting or staging areas for waterfowl. That the latter areas should be identified for protective or rehabilitative measures has recently been recognized (IJC/RAB 1977).

There are really two interrelated strategies to be worked out. As discussed in previous chapters, one would be the technical means to rehabilitate an area towards a preferred ecosystem state, including also the means necessary to maintain it in that state. The second is the strategy to implement the strategy, set out as specifications for the inter-organizational design and processes to do it. Elements of the former have been identified with reference to continuing stress factors identified in Green Bay and Bay of Quinte for example, as well as various ways of removing stress and the likely or preferred ecosystem outcomes.

Given the technical specifications for an ecosystem rehabilitation strategy for a designated area within the Great Lakes ecosystem, two sets of tasks must be carried out to deal with the institutional questions. The first would be to "map" the relevant **inter-organizational sub-system** taking into account points noted previously. The second would be to initiate what ideally should become a self-directed process towards moulding the sub-system into a functionally coherent, cooperative endeavor for implementing the strategy. The first may well be the easier of the two.

To "map" the existing components of the sub-system, it would be necessary to review the technical functions and activities required by the strategy and then identify which governmental or other organizations currently have responsibility for them or the expertise to contribute. Drawing up a matrix may be a helpful way to proceed. Table 5.4 outlines an approach to this, using the basic components for strategies given in Chapter 3.

Matrices tend to exaggerate the dispersion and fragmentation of responsibilities since they do not reveal differing degrees of involvement among the organizations identified. They also cannot easily distinguish between what individual organizations may be empowered to do from what they in fact concentrate on doing. Nevertheless, with an awareness of this, attention can be paid to discovering both the major thrust of activities, and whatever coordination mechanisms may have been set up to strengthen collective effort.

Draft matrices then need reviewing for obvious structural gaps, that is to see whether some on-going organization and program covers all the

Table 5.4. Possible format for "mapping" an inter-organizational system for implementing an ecosystem rehabilitation strategy.

		Organizations involved		
		Governmental, by jurisdiction		Non-governmental, by jurisdiction
		Agency X	Agency Y	
Rehabilitation techniques	Planning and management functions	Statute A Statute B etc.	Statute E Statute F etc.	Organization L Organization M etc.
Reduction of nutrient loads	Research/surveys Planning Operations Funding Regulations			
Microcontaminant control	Research/surveys etc., as above			
Fishery Management	Research/surveys etc., as above			
Physical/hydro-dynamic alterations	Research/surveys etc., as above			
Response to major accidents	Research/surveys etc., as above			

necessary components for the strategy needed in the designated geographic area of interest. The organizations identified in this exercise should be involved in a review of these preliminary analyses for accuracy of presentations and clarification of information. Besides identifying structural gaps which would have to be filled, the sufficiency of ongoing programs which seem to "cover" components of the strategy needs reviewing. Questions to be raised include: clarity of authorization to move more directly into rehabilitation activities; relevance of current program priorities to rehabilitation; mix of expertise available for the effort; sufficiency of overall program resources; and willingness to commit resources to rehabilitation activities.

It is also necessary to identify "actors" whose interests one way or another would be affected by the strategy, but they would not be involved directly in its implementation. They could probably be identified reasonably well through consultations with other "actors" who have been identified. There may be difficulty in deciding on "actors" who are non-resident yet legitimately concerned, a situation quite analogous to that encountered in public participation debates. The process of implementing the strategy remains relatively open.

One way of summarizing a descriptive analysis of the inter-organizational sub-system would be to identify the key actor groups according to their likely degree of involvement in the strategy. This could follow a distinction used by Gibbons and Voyer (1974) which classified actors in a system according to those which were central to the process and continuously involved, those which played a secondary support role or were intermittently involved, and those which were not involved but should be for various reasons. In a situation of rivalry and conflict, the same classification might be given to competing sub-systems of actors.

Another way of viewing the mapping activity would be to utilize the concept of leverage points in the process of policy formation and implementation (Gergen, 1968). Basically one assumes that not all members of society are involved in the decision-making process. Rather the approach is to identify and focus upon those individuals and organizations whose roles are central to the decision-making or policy process under review. Gergen's concept is based upon the premise that the key individuals participating in the policy formation /policy implementation process may be represented as a point in the three dimensional leverage space. One dimension of leverage specifies issue relevance for the individual. A second dimension of leverage represents the different resources the individual brings to the process. The third dimension relates to the personal efficacy, i.e., how effective is the individual in the context of this specific policy formation activity. The leverage approach to institutional analysis together with the mapping idea both direct the attention of the investigator to the dynamic qualities associated with the policy formulation/implementation process. Both methods provide a systematic approach to be used in the evaluation of institutional arrangements for rehabilitation.

The initiation of whatever needs to be done to fill major functional gaps revealed by the "mapping" of the inter-organizational system already in place, of building the necessary communication and cooperation linkages where these need to be established and strengthened, and the general mobilization of the system would probably fall first and foremost on the major "stake holders." These are the "actors" most committed to seeing ecological rehabilitation brought about.

There are at best only a few general guidelines which can be suggested for the collaborative inter-organizational processes required to work towards achieving some ecosystem rehabilitation goal (Table 5.5). Much of the vast amount of writing on organizational management and administration deals almost exclusively with single organizations either from the viewpoint of carrying out executive decision-making responsibilities, or from the viewpoint of the internal social dynamics among people within the organization. Much of the literature on inter-organizational systems has generally been directed towards questions of the equilibrating mechanisms of a market economy, the deliberate balancing acts of elected officials faced with conflicting special interest lobbies and expressed public concerns, or the kinds of negotiating tactics that the management of one organization might undertake with another to meet mutual interests. While these give important insights into perceptions and behaviors of "actors" in any complex inter-organizational system, the area of greatest interest for ecological rehabilitation strategies is the need to consider the conscious "design" of inter-organizational systems of relationships directed towards achieving rehabilitation as a policy goal. The "design specifications" would have to go beyond exclusive reliance on exhortation, regulation and fiscal measures which are so commonly used to steer the collective behavior of individual organizations towards some preferred social outcome.

It can be mentioned in passing that this kind of challenge-the need to think through what inter-organizational processes are more likely to achieve agreed upon social goals which transcend the particular objectives of each component "actor'‘-has come up elsewhere in society. It is a challenge posed for example by the difficulties in delivering comprehensive health and social services, developing multi-modal trans-

Table 5.5. Guidelines for inter-organizational processes

There is no magic recipe for bringing about productive collaboration among an array of organizations each of which can contribute towards achieving some agreed social goal. But among the general guidelines suggested by various writers are:

I. Articulate a clear social policy goal from which to judge collective accountability.
2. View the whole process as one of mutual learning.
3. Keep it open to new perceptions, new information and new participants.
4. Change reward systems to reinforce cooperative approach and reduce dominance of individual organization objectives and careerism as ends in themselves.
5. Open up the decision processes to a wider degree of public inspection and involvement.

portation systems or achieving regional economic development. These are situations which transcend the understanding and expertise of any one organization, where market mechanisms alone do not generate acceptable outcomes, and the idea of creating some super-bureaucracy to embrace the entire scope of these situations is absurd. In more localized contexts, it is also posed by the severe social problems of decayed urban neighborhoods in derelict industrial areas. These too are degraded environments which need rehabilitation.

There are clear analogies then between these societal situations and the Great Lakes ecosystems in terms of the inter-organizational systems which may be needed to deal with them. Some useful insights can be gained from writings about the dilemmas posed by the societal complexities noted above. While much of the material is still tentative and exploratory, the main theme running through the discussions about creating effective inter-organizational processes is the need to develop the communication flows and behavioral characteristics which lead to strengthened trust and collaboration among all concerned. One key to a successful process is to view it as a mutual learning situation which is deliberately kept open to new perceptions, new information and new participants. To the extent this is done, the inter-organizational arrangements remain capable of responding and adapting to changing circumstances and to heightened understanding of problems and alternatives for dealing with them. Conflicting views and competition are not overlooked by this approach, but they are consciously directed more towards seeking alternative proposals and advice from a variety of sources.

This somewhat idealized view of what to strive for in inter-organizational collaborative processes is usually contrasted with the perceived shortcomings of competitive bureaucracy in government, corporate and special interest organizations wherein organizational objectives and individual careerism so often become ends in themselves. Discussions about lessening this aspect of organizational behavior often stress the importance of changing the basic reward systems within institutions, opening up decision processes to a wider degree of public inspection and involvement, and articulating a clear social policy goal which serves as a larger framework within which the social accountability of various "actors" contributions can be judged. Some salient discussions of those kinds of issues may be found for example in the writings of Emery and Trist (1973), Friend, Power and Yewlett (1974), Chevalier and Bums (1977), Schnaiberg (1977), and Trist (1977).

There are also now a wide array of means for facilitating productive collaborative efforts among individuals and groups which could be incorporated into ecosystem rehabilitation strategies. Besides the group dynamic techniques associated with "modem management," computer modelling exercises have heuristic potential for bringing together scientific understanding with management needs. Holling (1978) has reviewed several experiments with this approach in a variety of contexts, some of which are quite comparable to ecosystem management issues in the Great

Lakes basin. The sensitive use of modelling can also be directed towards understanding some inter-organizational processes among "actor" groups and options for strengthening collective consensus about carrying out some course of action (Yaffee 1976; Jeffers 1978).

The main conclusion to be drawn then is that the pursuit of rehabilitation for Great Lakes ecosystems may in some particular areas also require new ground to be broken for designing the institutional arrangements and the collaborative processes necessary to achieve it (Table 5.6). This means that much can usefully be learned from the implementation process itself, and this should be monitored along with its results. If set in the sociological tradition of "grounded theory" (e.g. Glaser and Strauss 1975) using the approach for participatory involvement in real organizational processes as advocated for example by Rowbottom (1977), then the experiences gained from pursuing the strategies advocated in this report may cast some light on how to approach other areas of society where institutional change and innovation are sorely needed.

Table 5.6. An emerging federalism for the Great Lakes.

Strengthening inter-governmental cooperation on Great Lakes matters raises the issue of which functions and activities are best done at which levels, i.e. the classic problem of federalism. The following are some suggestions posed by various people.

1. Binational basin-wide level
   a. consultations on common goals, program guidelines;
   b. monitoring events, activities, results;
   c. anticipatory planning; and
   d. informal resolution of conflicts.
2. Lake Basin, sub-basin level
   a. close collaboration of "opposite number" agencies at State-Provincial level; and
   b. special management arrangements for particular problem areas (i.e. bays, harbors, environmentally-sensitive areas).

6. REHABILITATING PARTICULAR ECOSYSTEMS

Strategies for rehabilitating Great Lakes ecosystems have to be devised for ecologically integrated sub-components of the Great Lakes basin. The strategies have to address the particular conditions of each area, especially the mix of stresses affecting it. The question then is whether or not the general approach towards rehabilitation outlined in the foregoing chapters can be applied helpfully towards delineating workable strategies for particular smaller ecosystems.

This question was explored with two particular ecosystems: Green Bay, Lake Michigan and the Bay of Quinte, Lake Ontario. These two areas were chosen because:

a) they were known to have been degraded by various stress factors;

b) considerable multidisciplinary research has been carried out on them;
c) they exemplify both United States and Canadian institutional arrangements; and
d) there was a group of knowledgeable persons who were known to be concerned about the deterioration of these ecosystems and interested in seeing how rehabilitative measures may be undertaken.

As part of our rehabilitation study, workshops were held in Green Bay, Wisconsin and Belleville, Ontario to "test" the general applicability of ecosystem rehabilitation for these two bays. Specific objectives of the workshops were:

a) To outline some possible scenarios for ecosystem rehabilitation in terms of preferred outcomes specified by a consistent set of ecological indicators and the ecosystem conditions necessary to sustain them;
b) To identify strategies to bring these about;
c) To identify the likely benefits of achieving (a) and the likely costs of (b);
d) To identify the main organizations and groups who would have to be involved in the strategies and/or who would be affected by the outcomes; and
e) To propose some next steps in terms of research and information gathering priorities, and the arrangements to be worked out among the identified groups to initiate and pursue rehabilitation strategies.

The workshop participants included some people who were directly involved with research relating to the bay in question, others who were knowledgeable about the local economy and land use issues, and some members of our study group. Discussions were oriented initially by reference to the Chapter 3 material that outlined a typology of ecosystem stresses, corrective measures, and general assessments of feasibility. Each workshop reviewed these to identify which stresses impacted most heavily on the bay, the possible interactive effects among them and the associated consequences. Discussions then explored means of relieving stresses, including the more likely ecological outcomes from doing so, and some of the related economic and institutional questions raised by rehabilitation strategies dealing with stress alleviation.

The summary notes which follow are intended mainly to illustrate the kind of results which can be generated from this process. While the observations reported do reflect the considered judgement of the workshop participants, these must be taken only as preliminary conclusions. They serve to identify topics in need of more information, clarification and analyses.

Bay of Quinte

The Bay of Quinte lies along the northeast shore of Lake Ontario between Prince Edward County peninsula and the mainland (Figure 6.1). It is a Z-shaped configuration, and becomes progressively wider and deeper from the upper to lower end. Altogether it is about 86 km long and has a total area of 254 km^2 with a mean depth of about 9 m (Hurley and Christie 1977). The major centers of population are at the upper end of the bay.

The more recent history of the Bay of Quinte can be described as a "mini Lake Erie." The bay experienced accelerated cultural eutrophication together with overfishing after the mid-1940's which subsequently generated an array of associated problems. These latter included: a proliferation of higher aquatic vegetation throughout the 1950's until algal densities themselves became so high as to shade out these plants during the 1960's; increasing problems at water intakes for municipalities and private residences; a collapse of the whitefish runs by the late 1950's and of the walleye sports fishery in the early 1960's; declines in the bass and pike fisheries; and a rapid increase of less desirable exotics, especially white perch and alewives. By the early 1970's the bay was offering a challenge both for water quality management and fishery management.

Consultations initiated in early 1971 led to the establishment of "Project Quinte," an informal cooperative arrangement among research limnologists, fishery biologists, and pollution control engineers associated with the Canada Centre for Inland Waters, the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment respectively. University personnel have also contributed. Increasingly stringent measures to reduce phosphorus from municipal waste treatment plant discharges into the bay were introduced by the Ministry of Environment beginning in 1975 which resulted in a significant decrease in phosphorus loadings by 1978. "Project Quinte" is an informally coordinated set of studies on the aquatic ecosystem which serves to monitor the recovery of the bay as well as deepen the understanding of ecosystem dynamics. The whole program consists of five years of "pre-treatment" observations from the ongoing research during 1972-77 and five years of response measurement, 1978-82. Particular attention is being directed by those studies to questions such as the role of residual phosphorus in bottom sediments, the macrophyte succession during a recovery phase, and changes in the relative abundance of species of fish (Christie 1978b).

By the time our workshop was held, in May 1979, early evidence of natural recovery processes had been gathered for the bay. This was reflected by various limnological indicators, and a sudden increase in the populations of walleye and whitefish and sudden marked declines in white perch and alewives. To some extent therefore, recovery was beginning to occur. The central question then posed was whether phosphorus control was in itself sufficient for a full-scale rehabilitation strategy; or should

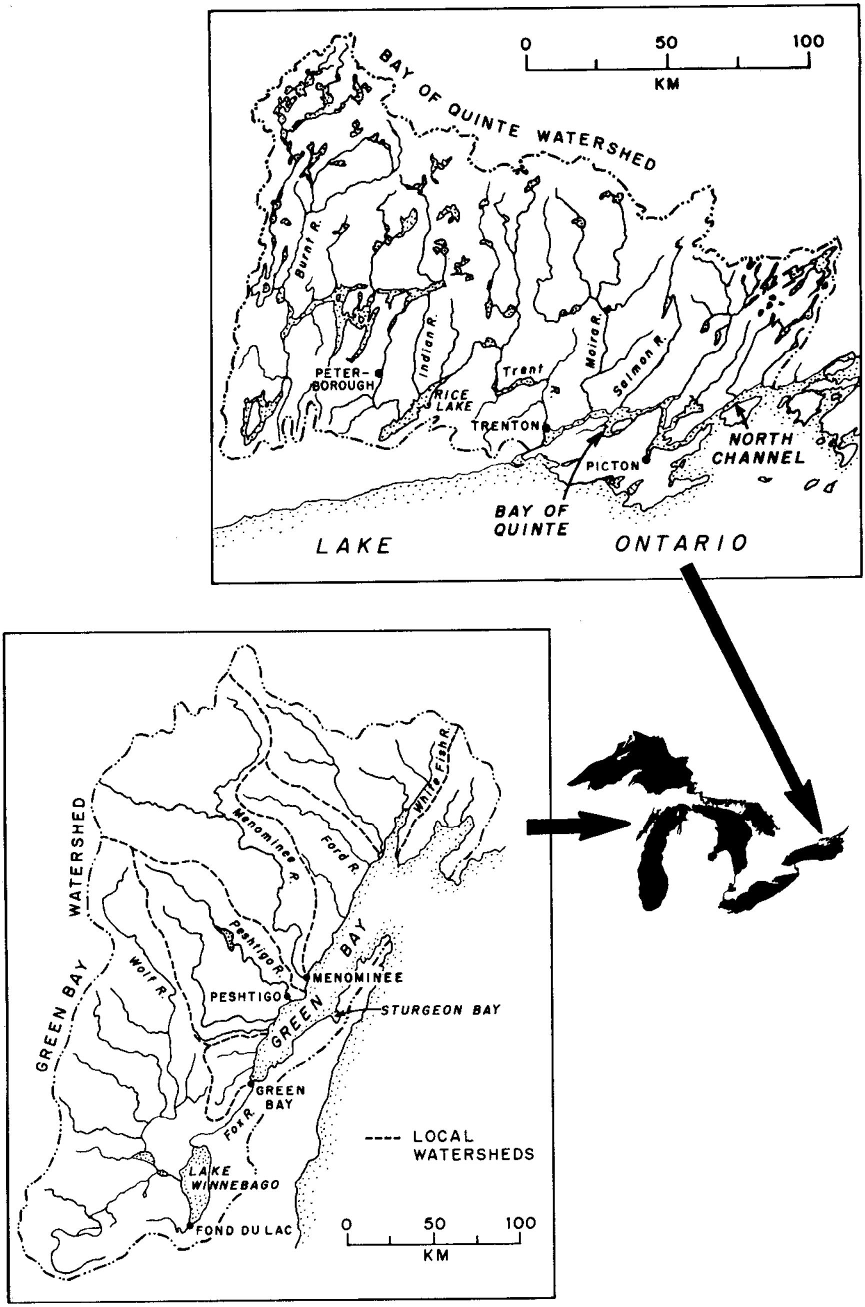

Figure 6.1. Green Bay and Bay of Quinte workshops assessed the rehabilitation prospects for these two bays.

additional management measures be considered for implementation after 1982 when the five year response measurement period will have ended?

Table 6.1 lists some of the perceived stresses impacting on the Bay of Quinte in descending order of their perceived importance. Table 6.2 outlines some possible "scenarios" of changes which could occur in the bay.

The preferred outcome of the group would be an ecological situation characterized by relatively clear water, a heterogeneous mosaic of aquatic vegetation and a bay fishery based on large percids, centrarchids and esocids. This kind of rehabilitated system would also meet recreation and tourism interests, increasing the basis of the local economy, and safeguard local water supplies drawn from the bay.

There were three particularly important problems identified that would require measures other than phosphorus control to achieve.

One was the question of controlling or "purging" micro-contaminants to enhance the utility of a rehabilitated fishery. Specific measures to be taken were not clear nor was it clear whether they could be handled sufficiently well at the level of the bay ecosystem. Nevertheless, it was agreed that this issue needed to be addressed as an integral part of a rehabilitation strategy.

The second, was the possibility that the natural recovery process may lead the bay through the reverse sequence of its eutrophication phases such that before long, aquatic weed growth will again become a nuisance problem impacting heavily on water-based recreation interests. This would require additional rehabilitative measures to accompany continued reductions of nutrient loadings.

The third was a question of what active fishery management measures would be required to create and maintain stable communities of desirable fish species. This question remains open.

Table 6.1. Preliminary list of stresses affecting the Bay of Quinte ecosystem in descending order of perceived importance.

Nutrient loadings
Polychlorinated biphenyls
Arsenic residues from mine wastes
Destruction of spawning habitats
Exotic fish in the system
Overfishing of preferred species
Unknown toxics or hazardous substances in the system
Destruction of marshes/wetlands
Biochemical oxygen demand, seasonal from canning industry
Thermal discharge of power station
Blocked spawning runs on streams
Entrainment/impingement at water intakes
Suspended solids entering system
Wastes from wood-using industries
Shoreline development/shoreworks
Potential mineral extraction activities
Major accidents impacting on the bay

Table 6.2. Some possible scenarios for future changes in the Bay of Quinte ecosystem.

Intervention	Possible outcome	Additional measures
Point source phosphorus control, e.g. to 0.5 mg/liter as specified for the summer of 1979	Clear water, macrophyte mosaic, large percids, centrarchids.	Fishery management to reduce small planktivores.
	Some turbidity, weed-choked with macrophytes, small centrarchids, gar, etc.	Mitigative measures to reduce weeds.
	Unclear water, algae dominant, white perch, gizzard shad.	Non-point control over nutrients, in farmers' fields and in the towns.
	Temporary improvement for a decade or two until further urban growth again causes eutrophication in spite of best practicable controls.	Limit population increases in the watershed and/or divert effluent to Lake Ontario

The workshop discussions did not deal very much with associated economic and institutional questions. However, there were no obvious difficulties apparent in terms of conflicts between short-term interests of particular groups and long-term rehabilitation strategies, nor did there seem to be any serious difficulty in "mapping" the groups that need to become involved in the larger effort. In general, the approach was deemed workable and helpful in developing some of the specifications for an effective ecosystem rehabilitation strategy in this area.

Green Bay

Green Bay, on the northwest side of Lake Michigan, is an estuary about 190 km long with an average width of 37 km and a mean depth of 20 m. The entire Green Bay watershed drains some 40,000 km^2, about two-thirds of which is in Wisconsin and the remainder in Michigan's Upper Peninsula (Fig. 6.1). Biologically, it is one of the most productive and important ecosystems of Lake Michigan. The extensive research on Green Bay (Bertrand et al. 1976, Garsow and Harris 1978) provides a basis for rehabilitation efforts.

The environmental quality of the bay had been significantly degraded by earlier forest exploitation, agricultural land-clearing and human settlement in the drainage basin. In more recent times the bay continues to be impacted by industrial developments along the lower Fox River, the main tributary river entering the bay, and to a lesser extent by shoreline developments for recreational purposes. In general the southern end of the bay remains heavily polluted from excessive nutrients, industrial wastes, and heavy sedimentation. Overfishing has been common and stocks of several preferred species have collapsed. Exotic fishes are now abundant. The quality of the recreational opportunities in the lower bay remains low.

Hope for improvements have been raised recently by more stringent waste treatment measures that are now resulting in major reductions of the biochemical oxygen demand loads entering the bay especially from the pulp and paper industries located on the Fox River. The Lake Michigan Federation has expressed strong interest in improving the bay's environmental quality, and researchers are launching a new set of multidisciplinary studies under the University of Wisconsin Sea Grant College Program. This collective effort seeks ways to improve resource production and environmental quality in the bay and its drainage basin. Green Bay citizens, researchers, and managers have already begun to address the applicability of ecosystem rehabilitation approaches like those outlined in preceding sections.

The central question posed in our Green Bay workshop was what array of stresses would have to be relaxed to ensure general improvements and what measures could be taken to achieve this? No explicit scenarios for a completely rehabilitated system could yet be specified. Rather it was more a matter of judging which among a variety of possible improvements, all of which are desirable, might also be feasible at present. Table 6.3 lists the perceived stresses impacting on Green Bay in descending order of their importance as viewed by the workshop participants.

Three scenarios in regard to fisheries were discussed in detail and elaborated: (1) PCB residue guideline decreasing from 5 ppm to 2 ppm; (2) overfishing and entrainment and impingement in regard to yellow perch; and (3) removal of dams to allow spawning access to rivers. All three are characteristic of the interactive aspects of stresses and rehabilitative measures: (1) fisheries x microcontaminants; (2) fisheries x use of water for cooling; and (3) fisheries x stream modification.

Scenario 1: Stress resulting from PCB concentrations and a guideline decrease to 2 ppm.

The most valuable commercial fishery in the bay is for lake whitefish. Unfortunately most lake whitefish in Green Bay over 48 cm (19 in) will probably not pass Food and Drug Administration guidelines of 2 ppm. To maintain this commercial fishery a "slot" size limit of 38–46 cm (15-18 in) may be required.

Simultaneously, every effort should be made to put pressure on the alewife population by saturation stocking of predators, with emphasis on native species, i.e. lake trout and walleye. Chinook and brown trout

Table 6.3. Preliminary list of stresses affecting the Green Bay ecosystem in descending order of their perceived importance.

Polychlorinated biphenyls
Nutrient loadings
Overfishing of preferred species
Exotic fish species in the ecosystem
Dredging and landfill operations
Destruction of spawning habitats
Biochemical oxygen demand from industrial waste
Unknown toxics or hazardous substances in the system
Suspended solids entering system
Major accidents impacting on the bay
Blocked spawning runs on tributary rivers
Heavy metals in the system
Shoreworks and off-shore development
Petroleum wastes
Entrainment/impingement at water intakes
Effects of large vessels moving through the system
Management of water levels on major rivers
Thermal discharge from power plants
Potential mineral extraction activities
De-icing salts from road runoff
Ice control measures
Water diversions

increases to be considered as well. Addition of large predators would require that harvest of whitefish be restricted to entrapment gear only to eliminate incidental gill net catch of lake trout and Pacific salmon. Sport harvest of lake trout should also be closed.

Theoretically, the preceding actions should reduce both alewife and smelt stocks which should then decrease their negative interactions with lake herring and emerald shiners. Any additional exploitation of smelt and alewife should be encouraged be it of sport or commercial origin. Chances for reproduction of lake trout, a prime goal, should be enhanced.

Questions requiring investigation prior to initiating action:

1. Do data exist to allow harvest of 38 cm (15 in) whitefish without danger?
2. What is the ideal carrying capacity for apex predators in Green Bay? What number of lake trout should be stocked?
3. What are dangers to other native forage species, i.e. sculpin, troutperch, spottail shiner, stickleback?
4. What other low fat species with less PCBs might fishing and management efforts be directed towards (northern pike, smallmouth bass)?

Coordination between Michigan and Wisconsin is essential to such efforts.

Scenario 2: Stresses on yellow perch of overfishing, impingement-entrainment, and spawning habitat destruction.

Current yellow perch stocks depend largely on only one year class for spawning. Efforts should be made to reduce exploitation to alleviate this dependency which may contribute to widely fluctuating populations and harvest. At the same time, power plant and industrial water intakes must be redesigned to decrease and/or eliminate impingement and entrainment to allow increased recruitment. Harvest of underutilized species should be encouraged to spread fishing pressure over several species.

Scenario 3: Removal of dams to allow spawning access to fishes.

Removal of dams such as on the Peshtigo River or Oconto River may be desirable for increased access to prime spawning grounds for common suckers, walleyes, salmonids, and lake sturgeon.

Questions/obstacles:

1. Sea lamprey would benefit and require additional control.
2. Political and social objections may occur, for example, conflicts with power generation.

One scenario was discussed in detail regarding dredge disposal, polluted sediments, artificial islands, marsh filling, and waterfowl nesting and fish spawning habitat. The complexity of this set of interacting stresses and potential stress release is apparent. The group believed that the detailed feasibility of rehabilitative actions in the lower bay deserved serious attention. What is the potential for building artificial islands with dredge spoils rather than filling existing wetlands with dredge spoils, containing any polluted sediments in the island, and topping off the materials such that useful waterfowl nesting areas and fish habitat are formed rather than destroyed? Some of the considerations of a related proposal were discussed by Mortimer (1978).

Several useful suggestions for developing a rehabilitation strategy for smaller ecosystems arose during this workshop. One was to prepare matrices which flag the nature and intensity of ecological interactions among the effects of different stresses (Table 6.4) as well as the rehabilitative measures applied to these stresses. Rehabilitation strategies must clearly take such interactions into account. Parenthetically it was noted with some sadness that deleterious effects of different stresses seldom cancel each other, but often interact additively or even synergistically, i.e., multiplicatively. Fortunately it was also noted in the evaluation of interactions among the effects of rehabilitative measures, that positive interactions were common and often synergistic. In other words for example, actions to rehabilitate in relation to eutrophication or microcontaminants had a favorable influence on fish communities. We also noted that the interaction effects of many rehabilitation measures were poorly understood and attempting to evaluate them taxed our imagination.

When reviewing the priority stress factors, three helpful questions arose:

Table 6.4. Possible interactive effects between direct physical stresses and stresses arising from activities in the watershed on the Green Bay ecosystem.

	Nutrients	Spawning habitat destruction	BOD	Suspended solids	Catastrophic events	Blocked spawning runs	Petro wastes	Drainage
Physical stresses								
Dredging	-	+	0	+	0	0	0	+
Filling	0	+	0	0	0	0	0	0
Sedimentation	+	+	+	+	0	0	+	+
Shore works	0	∓	0	0	0	+	0	+
Offshore structures	0	∓	0	0	0	∓	0	0
Natural stresses								
(wind, water levels fluctuations, ice)	+	+	+	+	+	0	0	0

+ = Additive or multiplicative interaction
0 = No interaction, effects are independent
\- = Cancellation or otherwise offsetting effects

Can rehabilitative objectives be set for dealing with a recognized stress, for example setting specific de-loading targets, defining restrictions to be placed on resource uses, or redesigning structures impacting on the ecosystem?

Can alternative means for reaching these objectives be described so that we know in principle how to do it?

Does some government agency or other organization have the authority and program expertise to carry out whatever is required by the alternative means?

If the answer to all these questions is "yes," then one basic component for some overall rehabilitation program is already in place, and need only be reviewed for more "fine-tuning" in terms of meeting the needs of ecosystem rehabilitation. If one of these questions cannot be answered clearly or positively, then this in turn becomes a priority for information gathering, analyses or organizational action.

Another useful suggestion was to arrange whatever rehabilitative measures are judged desirable into sets according to their relative costs and political acceptability, and according to whether they could be implemented relatively quickly or only over the long-term (Table 6.5). This exercise helps focus attention on cost-benefit considerations and on understanding the trade-offs against other values and interests which will inevitably generate the most political interest.

Table 6.5. Ranking of rehabilitative measures by relative costs and political acceptability. Examples are among those that could be applied and have effects in the short term (less than 5 years).

Rehabilitative measure	Relative cost	Political acceptability
Create grassed waterways	low	high
Identify/evaluate toxic "hot spots" in bottom sediments	low	high
Restore macrophytes	low	high
Protective fencing along stream banks	low	medium
Protect existing storm water retention areas	low	medium
Harvest contaminated fish for short-term economic benefit	medium	medium
Regulations for sediment control at construction sites	medium	high
Create barrier bars in bay with inert clean materials	medium	high
Change manure handling practices	medium	medium
Creative use of non-polluted dredge spoils	medium	medium
Implementation of toxic control regulations	high	medium

Conclusions from the bay workshops

The overall approach to ecosystem rehabilitation outlined by this study is a useful framework for orienting collective effort towards working out strategies for smaller ecosystems. It helps define and bound the topics needing the most attention through more structured information gathering and analyses, and it helps remove the sense of overwhelmingly diffused complexity which so often impedes attempts to come to grips with ecosystem management issues.

The workshop device itself is a useful component in the overall strategy for implementing rehabilitation strategies. It is a process which generates useful suggestions applicable to a wider range of situations. It is a starting point for addressing specific issues and developing action plans for rehabilitating Great Lakes ecosystems.

7. RECOMMENDATIONS

As follow-up measures to this study on "Rehabilitating Great Lakes Ecosystems," we urge the Great Lakes Fishery Commission to do the following.

Disseminate the report

1. Publish the study as a contribution in its Technical Report series. It should go to press very soon.

2. Prepare a more popularized, illustrated version to help foster wider public understanding and interest in ecosystem rehabilitation and arrange for its publication and sale.
3. Offer to arrange briefings on the essence of the study to interested elected officials and senior administrators, especially for agencies in both countries which clearly have a major role in rehabilitating the Great Lakes.

Use the report as a working document

4. Refer the report to the Strategic Great Lakes Fishery Management Plan developers for their use as a basic document.
5. Use the report to explore with the International Joint Commission and the Great Lakes Basin Commission ways in which all three commissions can pursue an ecosystem rehabilitation goal for the lakes in a more mutually supportive way.

Initiate action planning

6. Initiate, through the Scientific Advisory Committee and the Lake Committees, workshops to explore ecosystem rehabilitation strategies for other selected areas in the Great Lakes, e.g. Burlington Bay, western Lake Erie, Lake St. Clair, Saginaw Bay, southern Lake Michigan, Duluth-Superior. The objectives would be to initiate mutual contacts among individuals from various organizations which could contribute to rehabilitation strategies for these areas, outline the approaches proposed in this study, propagate the experience of Green Bay and Bay of Quinte, and catalyze formation of local rehabilitation groups to work in these areas.
7. In consultation with the International Joint Commission, formally request the Governments of the United States and Canada to submit a reference on rehabilitating Great Lakes ecosystems to the IJC under Article 9 of the Boundary Water Treaty of 1909 and noting also Article VII l(g) of the Great Lakes Water Quality Agreement of 1978. The main purpose of the reference is to develop an ecosystem rehabilitation action plan for the entire Great Lakes which would consider the system-wide requirements needed to complement and support strategies defined for the smaller ecosystem components (i.e., 6 above), and at the same time delineate measures which help implement the "ecosystem quality" commitment of the IJC. The GLFC should offer to take a lead role in helping IJC carry out the terms of such a reference.

Support research on ecosystem rehabilitation issues

8. Continue working informally with groups like the University of Wisconsin Sea Grant College Program at Green Bay or Project

Quinte in their efforts to delineate more specific rehabilitation action plans. Special attention should be given to monitoring the processes which are followed to do this in order to recommend effective processes others could adopt elsewhere within the basin.

9. Convene workshops or working groups to coordinate and encourage exploratory studies on issues relating to ecosystem rehabilitation such as:

   -refinements in economic valuations of fisheries and fishery-related economic activities;
   -review of issues related to relatively unexplored values of ecosystems, such as "existence values," option values, and uncertain futures;
   -state of the art in making empirical predictions of ecosystem attributes sought through management interventions; and
   -ecosystem responses to rehabilitation measures, especially sequences, time lags, etc.

10. Have a review and evaluation made of its activities which have contributed to ecosystem rehabilitation, e.g., the sea lamprey control programs, and the protocols established to assess the proposed introduction of exotic fish into the lakes.

8. REFERENCES

ADELMAN, I. R., and L. L. SMITH, JR.
1970. Effect of hydrogen sulfide on northern pike eggs and sac fry. Trans Amer. Fish Soc. 99:501–509.

APPLEGATE, V. C.
1950. Natural history of the sea lamprey. USFWS Spec. Sci. Rep. Fisheries 55. 237 pp.

APPLEGATE, V. C., J. H. HOWELL, J. W. MOFFETT, B. G. H. JOHNSON, and M. A. SMITH
1961. Use of 3 trifluormethyl-4-nitrophenol as a selective sea lamprey larvicide. Great Lakes Fishery Comm. Tech. Rep. No. 1. 35 pp.

ARMSTRONG, D. E., M. A. ANDERSON, J. R. PERRY, and D. FLATNESS
1979. Availability of pollutants associated with suspended or settled river sediments which gain access to the Great Lakes. Progress Report, EPA Contract No. 68-01-4479. 98 pp.

BALDWIN, N. S., and R. W. SAALFELD
1962. Commercial fish production in the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. 3. 166 pp. (1979 revised edition in press).

BAYFIELD, H. W.
1816-1824. Notes relating to the survey of Great Lakes. Public Archives of Canada. MG 24 F.

BEETON, A. M.
196.5. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceanogr. 10:240–254.
1969. Changes in the environment and biota of the Great Lakes. Pages 150-187 *in* Eutrophication: causes, consequences, correctives. Nat. Acad. Sci., Washington, D.C.
1976. Effect of pollution on the trophic state of lakes. Great Lakes Res. Div., Great Lakes and Mar. Wat. Cent. Contr. No. 208. Univ. Michigan, Ann Arbor. 11 pp.

BEETON, A. M., and W. T. EDMONDSON
1972. The eutrophication problem. J. Fish. Res. Board Can. 29:673-682.
BERTRAND, G., J. LANG. and J. ROSS
1976. The Green Bay watershed: past, present, future. Madison, University Wisc. Sea Grant Coll. Prog. Tech. Rep. No. 229. 300 pp.
BISHOP, R. C., and K. SAMPLES
1978. Sport and commercial fishing interactions: an optimal control model with implications for policy and research. Univ. Wisconsin-Madison, Dept. Agr. Econ. Staff Pap. No. 146. 17 pp.
BISHOP, R. C., and D. L. VOGEL
1977. Power plant siting on Wisconsin's coasts: a case study of a displaceable use. Coastal Zone Mgmt. J. 3:363-384.
BJÖRK, S.
1972. Swedish lake restoration program gets results. Ambio 1: 154-165.
1974. European lake rehabilitation activities. Paper presented at Univ. Wisconsin-Madison Conference on Lake Protection and Management, 1974. Univ. Lund. Inst. Limnology. 23 pp.
BJÖRK, S., and 11 other contributors
1972. Ecosystem studies in connection with the restoration of lakes. Verh. Intemat. Verein. Limnol. 18:379-387.
BLUST, F. A.
1976. The U.S. lake survey, 1841-1974. Inland Seas 32(2):91-104.
BORGESON, D. P., ed.
1970. Coho salmon status report. Mich. Dept. Nat. Res. Fish Mgmt. Rep. 3. 31 pp.
BORGESON, D. P., and W. H. TODY
1967. Status report on Great Lakes Fisheries 1967. Mich. Dept. Cons., Fish. Mgmt. Rep. 2. 35 pp.
BORN, S. M.
1979. Lake rehabilitation: a status report. Environmental Mgmt. 3(2): 145-153.
BOTTS, L.
1979. The unanswered questions around winter navigation. Great Lakes Basin Comm., Great Lakes Communicator 9(5):3, 7.
BRIDGER, K. C.
1978. The Ogoki River diversion: reservoir, downstream, diversion channel and receiving water body effects. M.A. thesis. Dept. of Geography. Univ. Waterloo, Waterloo, Ontario.
BULKLEY, J. W., and A. P. MATHEWS.
1973. Water quality relationships in the Great Lakes: analyses of a survey questionnaire. Pages 872-879 in Proc. 16th Conf. Great Lakes Res.
BURNS, N. M., ed.
1976. Lake Erie in the early seventies. J. Fish. Res. Board Can. 33:351-643.
BURTON, I., R. W. KATES and G. F. WHITE
1978. The Environment as hazard. Oxford Univ. Press, New York. 240 pp.
CANADA SENATE
1975. Standing Committee on Foreign Affairs. Proc. respecting: Canadian relations with the United States, testimony. March 18, 1975. Issue 10:1-25.
CANADA-UNITED STATES UNIVERSITY SEMINAR.
1973. A proposal for improving the management of the Great Lakes of the United States and Canada. Cornell University, 76 pp.
CAIRNS, J., JR., K. L. DICKSON and E. E. HERRICKS, eds.
1977. Recovery and restoration of damaged ecosystems. Univ. Press of Virginia, Charlottesville. 53 I pp.
CHEVALIER M., and T. BURNS
1977. A field concept of public management. Environment Canada, Office of the Science Advisor, Ottawa. Report No. 14. 54 pp.

CHRISTIE, W. J.
1974. Changes in the fish species composition of the Great Lakes. J. Fish. Res. Board Can. 31:827-854.
1978a. A study of freshwater fishery regulations based on North American experience. Rome, Food and Agriculture Organization, FAO Fish. Tech. Pap. 180. 46 pp.
1978b. The rationale for Project Quinte. Mimeographed discussion notes, 4 pp.
CHRISTIE, W. J., J. M. FRASER, and S. J. NEPSZY
1972. Effects of species introductions on salmonid communities in oligotrophic lakes. J. Fish. Res. Board Can. 29:969–973.
COLBY, P. J.
1971. Alewife dieoffs: why do they occur? Limnos. 4(2): 18-27.
COLBY, P. J., ed.
1977. Proceedings of the 1976 Percid International Symposium (PERCIS). J. Fish. Res. Board Can. 34: 1447-1999.
COLBY, P. J., and L. L. SMITH, Jr.
1967. Survival of walleye eggs and fry on paper fiber sludge deposits in the Rainy River, Minnesota. Trans. Amer. Fish. Soc. 96:278–296.
COLBY, P. J., G. R. SPANGLER, D. A. HURLEY, and A. M. McCOMBIE
1972. Effects of eutrophication on salmonid communities in oligotrophic lakes. J. Fish. Res. Board Can. 29:975-983.
COMPTROLLER GENERAL OF THE UNITED STATES
1977. Report to the Congress: the Great Lakes commercial fisheries past, present, and potential. U.S. Gen. Acctng. Office Rep. CD-77-%. 98pp.
CRAINE, L. E.
1972. Final report on institutional arrangements for the Great Lakes. Great Lakes Basin Commission, Ann Arbor. Unnumbered. (reproduced).
DAVIS, C. C.
1964. Evidence for eutrophication of Lake Erie from plankton records. Limnol. Oceanogr. 3:275-283.
1966. Plankton studies in the largest Great Lakes of the world. Great Lakes Research Div. Publ. No. 14:1-36.
DAY, J. C., J. A. FRASER, and R. D. KREUTZWISER
1977. Assessment of flood and erosion assistance programs, Rondeau coastal zone experience, Lake Erie. J. Great Lakes Res. 3:38-45.
DENISON, P. J., and F. C. ELDER
1970. Thermal inputs to the Great Lakes, 1968–2000. Proc. 13th Conf. Great Lakes Res: 811-828.
DUNST, R. C., S. M. BORN, P. D. VITORMARK, S. A. SMITH, S. A. NICHOLS, J. 0. PETERSON, B. R. KNAVER, S. L. SERNS, D. R. WINTER, and T. C. WIRTH
1974. Survey of lake rehabilitation techniques and experiences. Wis. Dept. Nat. Res. Tech. Bull. No. 75. 179 pp.
DWORSKY, L. B., G. R. FRANCIS, and C. R. SWEZEY
1974. Management of the international Great Lakes. Nat. Res. J. 14(1): 103-138.
DYMOND, J. R.
1964a. A history of ichthyology in Canada. Copeia 1964(1):2-33.
DYMOND, J. R., ed.
1964b. Fish and wildlife: a memorial to W. J. K. Harkness. Longmans Canada Ltd. Toronto. 2 14 pp.
EDMONDSON, W. T.
1973. Lake Washington. Pages 281-298 in C. R. Goldman, J. McEvoy III, and P. J. Richerson, eds. Environmental quality and water development. W. H. Freeman, San Francisco. 510 pp. (originally published as a report to the National Water Commission, Washington, D.C.).
EMERY, A. E., and K. H. LOFTUS
1972. A position paper on “once through cooling” in proposed electrical energy centres on the Great Lakes, Fisheries Branch, Ont. Min. Natural Res., Toronto. 39 pp.

EMERY, F. E., and E. L. TRIST
1973. Towards a social ecology. Plevium Publ. Corp., London. 239 pp.
FLOTARD, R.
1978. Degradability of PCBs in lake sediments. Ph.D. thesis (Water Chemistry), University of Wisconsin-Madison. 104 pp.
FORSBERG, C., B. HAWERMAN, and L. ULMGREN
1972. A programme for studies of the recovery of polluted lakes. Vatten 28: 156-161.
FORSBERG, C., S. -O RYDING, and A. CLAESSON
1975. Recovery of polluted lakes. A Swedish research program on the effects of advanced waste water and sewage diversion. Water Research 9:51-59.
FORSTER, D. L., and G. S. BECKER
1979. Erosion control: costs and income effects of alternative erosional control strategies, the Honey Creek Watershed. North Central J. of Agricultural Economics 1:53-60.
FRANCIS, G. R., and H. A. REGIER
1977. Proposal to establish a reference group on Great Lakes rehabilitation and restoration. Submitted to the Great Lakes Fishery Commission Annual Meeting, June 1977. Reprinted with minor revisions as: Let's rehabilitate and restore degraded ecosystems of the Great Lakes. Lakes Letter 8(3):2-9.
FRICK, H. C.
196.5. Economic aspects of the Great Lakes fisheries in Ontario. Bull. Fish. Res. Board Can. 149. 160 pp.
FRIEND, J. K., J. M. POWER, and C. J. L. YEWLETT
1974. Public planning: the inter-corporate dimension. Tavistock Publication, London. 534 pp.
GARSOW, V., and H. J. HARRIS, eds.
1978. Research needs for Green Bay. Univ. Wisc. Sea Grant Coll. Progr., Proc. of Sept. 1978 Green Bay Research Workshop. 184 pp.
GEIS, J. W.
1979. Shoreline processes affecting the distribution of wetland habitat. Trans. North Amer. Wildl. Nat. Resour. Conf. 44 (in press).
GELIN, C.
1978. The restoration of freshwater ecosystems in Sweden. Pages 323-336 in M. W. Holdgate and M. J. Woodman, eds. The breakdown and restoration of ecosystems. NATO Conf. Ser., l(3) 496 pp.
GERGEN, K. J.
1968. Assessing the leverage points in the process of policyformation. Pages 181-204 in R. A. Bauer and K. J. Gergen, eds. The study of policy formation. The Free Press, New York.
GHANBARI, M. R.
1977. Optimum allocation of a renewable resource: a bioeconomic model of the Great Lakes whitefish fishery. Ph.D. thesis, Dept. Agr. Econ. Michigan State Univ., East Lansing. 180 pp.
GIBBONS, M., and R. VOYER
1974. A technology assessment system: a case study of east coast offshore petroleum exploration.-Science Council of Canada, Background Study No. 30.
GLASER. B. G.. and A. L. STRAUSS.
1975. The discovery of grounded theory: strategies for qualitative research. Aldine Publ. Co., Chicago. 378 pp.
GOLDMAN, C. R.
1974. Eutrophication of Lake Tahoe emphasizing water quality. EPA-66 O/3-74-034. U.S. Gov. Print. Office, Washington, D.C. 408 pp.
GOOD, R. E., D. F. WHIGHAM, and R. L. Simpson, eds.
1978. Freshwater wetlands: ecological processes and management potential. Academic Press, New York.

GREAT LAKES BASIN COMMISSION
1978. Great Lakes Communicator 8(12), 9(1) and 9(2-3).
1979. Workshop on scientific basis for dealing with chemical toxic substances in the Great Lakes. (unpubl. rep.).
GLBC/EROSION AND SEDIMENTATION WORK GROUP
1975. Erosion and sedimentation. App. 18 to the Great Lakes Basin Framework Study, 127 pp.
GLBC/FISH WORK GROUP
1975. Fish. App. 8 to the Great Lakes Basin Framework Study. 290 pp.
GLBC/GREAT LAKES BASIN FRAMEWORK STUDY
1975- Report and appendices totalling 27 volumes.
1976.
GLBC/LEVELS AND FLOWS WORK GROUP
1975. Levels and flows. App. 11 to the Great Lakes Basin Framework Study, 207 pp.
GLBC/WATER QUALITY WORK GROUP
1975. Water quality. App. 17 to the Great Lakes Basin Framework Study, 228 pp.
GLBC/WATER SUPPLY WORK GROUP
1975. Water supply-municipal, industrial, and rural. App. 6 to the Great Lakes Basin Framework Study, 266 pp.
GREAT LAKES FISHERY COMMISSION
1973. Case histories of salmonid communities in Lakes Superior, Michigan, Huron, Erie and Ontario. Great Lakes Fish Comm. Fish. Rep. Nos. 19 to 23.
GRIMA, A. P.
1978. The use of content/contingency analysis in evaluating public hearings. Pages 84-90 in C. Schoenfeld and J. Disinger, eds.. Environmental education in action, III case studies of public involvement in environmental policy. ERIC Clearinghouse, Ohio State University, Columbus.
GRIMA, A. P., and C. WILSON-HODGES
1977. Regulation of Great Lakes levels: the public speaks out. J. Great Lakes Res. 3:240–257.
GULLAND, J. A., ed.
1977. Fish population dynamics. John Wiley & Sons, London. 372 pp.
GUNNERSON, C. G., and K. A. OAKLEY
1974. Review paper: binational abatement of boundary water pollution in the North American Great Lakes. Water Research. 8:713-724.
HAILE, C. L.
1977. Chlorinated hydrocarbons in the Lake Ontario and Lake Michigan ecosystems. Ph.D. thesis (Water Chemistry), University of Wisconsin-Madison. 115 pp.
HALL, J.
1978. Basin plan aims at toxic problems. Great Lakes Basin Comm., Great Lakes Communicator 8(12): 1-2.
HALLAM, J. C.
1959. Habitat and associated fauna of four species of fish in Ontario streams. J. Fish. Res. Board Can. 16:147-173.
HARTMAN, W. L.
1972. Lake Erie: effects of exploitation, environmental changes, and new species on the fishery resources. J. Fish. Res. Board Can. 29:899-912.
HARVEY, H. H.
1975. Fish populations in a large group of acid-stressed lakes. Verh. Internat. Verein. Limnol. 19:2406-2417.
HENNIGAN, R. D.
1969. The cost of improving water quality in the Great Lakes. Water and Wastes Eng. 6:A-28-A-31.
HENSON, E. B.
1966. A review of Great Lakes benthos research. Great Lakes Research Div. Publ. No. 14:37-54.

HERBICH, J. B.
1975. Environmental effects of dredging. Pages 519-534 in Coastal and deep-ocean dredging, Gulf. Publ. Co., Houston, Texas.
HERDENDORF, C. E., D. E. RATHKE, D. D. LARSON, and L. A. FAY
1977. Suspended sediment and plankton relationships in the Maumee River and Maumee Bay of Lake Erie. In Geobotany. R. E. Romas *ed,* Plenum Publ. Corp., New York.
HOLLING, C. S., ed.
1978. Adaptive environmental assessment and management. International Institute for Applied Systems Analysis. John Wiley and Sons, London. 377 pp.
HURLEY, D. A., and W. J. CHRISTIE
1977. Depreciation of the warm water fish community in the Bay of Quinte, Lake Ontario. J. Fish. Res. Board Can. 34:1849-1860.
HYNES, H. B. N.
1970. The ecology of running waters. Univ. Toronto Press, Toronto. 555 pp.
IJC
1977. Annual Report To Governments. Int. Joint Comm. 49 pp.
1978a. Annual Report To Governments. Int. Joint Comm. 110pp.
1978b. Great Lakes water quality agreements of 1978. 15 pp + 13 annexes.
IJC/ABATEMENT AND CONTROL OF POLLUTION FROM DREDGING ACTIVITIES WORK GROUP.
1975. Report. Int. Joint Comm. 227 pp.
IJC/INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES (PLUARG).
1977a. The legislative and institutional framework to control pollution from land use activities in the United States Great Lakes basin (E. Schweitzer, W. G. Stewart, and B. Roth). Pollution from Land Use Activities Reference Group, Int. Joint Comm. 3 volumes.
1977b. Control of water pollution from land use activities in the Great Lakes basin: an evaluation of legislative, regulatory, and administrative programs. J. F. Castrilli, ed.. Environmental Protection Service, Fed. Dept. Fisheries and Environment, Ontario Region, Govt. of Canada. 417 pp.
1978. Environmental management strategy for the Great Lakes system. Pollution from land use activities reference group. 173 pp.
IJC/GREAT LAKES RESEARCH ADVISORY BOARD
1978. Workshop on environmental mapping of the Great Lakes. Int. Joint Comm. 224 pp.
1978. The ecosystem approach. 47 pp.
IJC/GREAT LAKES SCIENCE ADVISORY BOARD.
1979. Annual Report of the Science Advisory Board. Int. Joint Comm., 109 pp.
IJC/TECHNICAL GROUP TO REVIEW PHOSPHORUS LOADINGS.
1978. Contribution of phosphorus to the Great Lakes from agricultural land in the Canadian Great Lakes basin. 56 pp.
IJC/INTERNATIONAL REFERENCE GROUP ON UPPER LAKES POLLUTION
1976. The waters of Lake Huron and Lake Superior. 5 vols.
IJC/GREAT LAKES WATER QUALITY BOARD.
1973- Great Lakes Water Quality Annual Reports.
1978.
JAWORSKI, E., and C. N. RAPHAEL
1976. Modification of coastal wetlands in southeastern Michigan and management alternatives. Michigan Academician 8(3):303-3 17.
1978. Existing and potential value of wetlands and bottomlands in the Sterling State Park area, Monroe County, Michigan. Prepared for U.S. EPA, Region V, Chicago. Eastern Michigan University, Ypsilanti, Michigan. 37 pp.
1979a. Impact of Great Lakes Water Level Fluctuations on Coastal Wetlands. 351 pp. Final Report, Office of Water Resources and Technology. E. Michigan University, Ypsilanti, Mich.

1979b. Mitigation of fish and wildlife habitat losses in Great Lakes coastal wetlands. Pages 152-156 in G. A. Swanson, tech. coord. The mitigation symposium: a national workshop on mitigating losses of fish and wildlife habitats. General Tech. Rep. RM-65. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colo.

JEFFERS, J. N. R.
1978. General principles for ecosystem definition and modelling. Pages 85-101 in M. W. Holdgate and M. J. Woodman, eds. The breakdown and restoration of ecosystems. NATO Conf. Ser., Ser. 1:Ecology, Vol. 3. 4% pp.

JOHNSON, M. G., and N. BERG
1979. A framework for nonpoint pollution control in the Great Lakes Basin. J. Soil and Water Conservation 34:6873.

KATES, R. W.
1978. Risk assessment of environmental hazard. SCOPE 8. John Wiley and Sons, New York 112 pp.

KELSO, J. R. M., and G. S. MILBURN
1979. Entrainment and impingement of fish by power plants which use once-through cooling process in the Great Lakes. J. Great Lakes Res. 5(2):182-194.

KEMP, A. L. W., C. A. MAcINNES and N. S. HARPER
1978. Sedimentation rates and revised sediment budget for Lake Erie. J. Great Lakes Res. (in press).

KENDALL, R. L., ed.
1978. Selected coolwater fishes of North America. Amer. Fish. Soc. Spec. Publ. No. 11. 437 pp.

KENT STATE UNIVERSITY
1975. Current institutional arrangements, Lake Erie Basin. Center for Urban Regionalism and Environmental Systems. 26 pp.

KRISHNER, L. D.
1968. Effects of diversions on the Great Lakes. U.S. Lake Survey Misc. Pap. No. 68-7.

KUTKUHN, J., W. HARTMAN, A. HOLDER, R. KENYON, S. KERR, A. LAMSA, S. NEPSZY; M. PATRIARCHE, R. SCHOLL, W. SHEPHERD, and G. SPANGLER
1976. First technical report of the GLFC Scientific Protocol Committee on Interagency Management of the Walleye Resource of Western Lake Erie. Great Lakes Fishery Comm. 31 pp. (mimeo).

LANDNER, L.
1976. Eutrophication of lakes, its causes, effects and means for control: with emphasis on rehabilitation. World Health Organization, Copenhagen. 78 pp.

LANGLOIS, T. H.
1945. Water, fishes and cropland management. Trans. 10th North Am. Wildl. Conf. 190–196.

LARK, J. G.
1973. An early record of sea lamprey from Lake Ontario. J. Fish. Res. Board Can. 30: 131-133.

LARKIN, P. A.
1977. An epitaph for the concept of maximum sustained yield. Trans. Amer. Fish. Soc. 106:1–11.

LAWRIE, A. H.
1970. The sea lamprey in the Great Lakes. Trans. Amer. Fish. Soc. 99:766–775.

LEACH. J. H.. M. G. JOHNSON, J. R. M. KELSO, J. HARTMANN, W. NÜMAN, and B. ENTZ
1977. Responses of percid fishes and their habitats to eutrophication. J. Fish. Res. Board Can. 34: 1964-1971.

LEE, G. F.
1971. Eutrophication. Pages 315-338 in Encyclopedia of chemical technology, sec. ed., John Wiley and Sons, New York.

LEMAN, A. M., and I. A. LEMAN, eds.
1976. Great Lakes megalopolis: from civilization to ecumenization. Canada Ministry of State for Urban Affairs, Ottawa 118 pp.
LEVERE, T. H., and R. A. JARRELL
1974. A curious field-book, science and society in Canadian history. Oxford Univ. Press, Toronto. 233 pp.
LIN, L., and S. GREGERMAN
1979. Background articles on winter navigation. Great Lakes Basin Comm., Great Lakes Communicator, 9(5): 1-7.
LOFTUS, K. H., ed.
1968. A symposium on introductions of exotic species. Ont. Dept. Lands and Forests. Research Br. Research Rep. 82. 111 pp.
LOFTUS, K. H.
1976. Science for Canada's fisheries rehabilitation needs. J. Fish. Res. Board Can. 33: 1822-1857.
LOFTUS, K. H., M. G. JOHNSON, and H. A. REGIER
1978. Federal-provincial strategic planning for Ontario fisheries: management strategy for the 1980s. J. Fish Res. Board Can. 35:916-927.
LOFTUS, K. H., and H. A. REGIER, eds.
1972. Proceedings of the symposium on salmonid communities in oligotrophic lakes (SCOL). J. Fish. Res. Board Can. 29:613-986.
LOGAN, T. J.
1978. Bioavailability of sediment phosphate. U.S. Army Corps of Engineers, Buffalo.
LUDWIGSON, J. 0.
1974. Two nations - one lake: science in support of Great Lakes management. Objectives and activities of the international field year on the Great Lakes. Canadian National Committee for the International Hydrological Decayed. Environment Canada, Ottawa. 145 pp.
MACARTHUR, D., and S. F. NAGY
1976. The economic impact of a ban on polychlorinated biphenyls. Pages 309-311 *in* Proc. 1975 Nat. Conf. on Polychlorinated Biphenyls. U.S. Environ. Protection Agency Office of Toxic Wastes, Washington, D.C.
MAcLAREN, J. W.
1976. Great Lakes users: municipal. Paper delivered to the Canadian Water Resources Association Toronto, June 1976.
1977. Saving the Great Lakes. J. Soil Water Cons., 32(3):116117.
MAGNUSON, J. J.
1976. Managing with exotics-a game of chance. Trans. Amer. Fish Soc. 105: 1-9.
MAGNUSON, J. J., H. A. REGIER, W. J. CHRISTIE and W. C. SONZOGNI
1979. TO rehabilitate and restore Great Lakes ecosystems. In J. Cairns, Jr., ed. Recovery of damaged ecosystems. Ann Arbor Sci. Publ., Ann Arbor, Mich. (in press).
MAHER, F.
1964. On the feasibility of introducing Kokanee, the landlocked sockeye salmon, *Oncorhynchus nerka* Kennerlyi, to the Great Lakes. Ont. Dep. Lands and Forests Sect. Rep. (Fish) No. 55.
MARSHALL, M., H. SPALDING, and D. A. WISMER
1977. A strategy to improve the management of the Great Lakes basin by modification of Canadian institutional arrangements. Univ. Waterloo Faculty Environ. Studies. (unpubl. rep.).
McANDREWS, J. H., A. A. BERT1 and G. NORRIS
1973. Key to the quaternary pollen and spores of the Great Lakes region. Life Sci. Misc. Publ., R. Ont. Mus., Toronto. 61 pp.
McCOMBIE, A. M.
1968. Changes in the physical and chemical environment of the Laurentian Great Lakes.

Pages 21-53 *in* K. H. Loftus, ed. A symposium of introductions of exotic species. Ontario Dept. Lands and Forests Res. Rep. No. 82.
McCRIMMON, H. R.
1954. Stream studies on planted Atlantic salmon. J. Fish Res. Board Can. 11:362-403.
McNAUGHT, D. C.
1975. A hypothesis to explain the succession from calanoids to cladocerans during eutrophication. Verh. Internat. Verein. Limnol. 19:724-731.
MOFFETT, J. W.
1957. Recent changes in the deep-water fish population of Lake Michigan. Trans. Amer. Fish. Soc. 86:393-408.
MOODIE, D. W.
1977. The Hudson's Bay Company's archives: a resource for historical geography. Canadian Geographer 21(3):268-274.
MORTIMER, C.
1979. Re islands off Milwaukee, personal communication. Univ. Wisconsin-Milwaukee.
NALEPA, T. F., and N. A. THOMAS
1978. Distribution of macrobenthic species in Lake Ontario in relation to sources of pollution and sediment parameters. In N. A. Thomas and W. J. Christie, eds. Status of the biota of Lake Ontario during IFYGL. (In press.)
NEIL, J. H.
1976. Distribution. Pages I-179 *in* A. Shear and D. E. Konasewich, eds. *Cladophora* in the Great Lakes. IJC Res. Adv. Board.
NELSON, J. G., and R. D. NEEDHAM, eds.
1979. The Lake Erie peninsulas: management issues and directions. Univ. Waterloo Fac. Environmental Studies, Contact 11(1): 1% pp.
NEPSZY, S. J., and J. H. LEACH
1973. First records of the Chinese mitten crab. *Eriocheir sinensis*. (Crustacea: Brachyura) from North America. J. Fish Res: Board Can. 30: 1909-1910.
NICHOLLS, K. H., D. W. STANDEN, G. J. HOPKINS, and E. C. CARNEY
1977. Declines in the near-shore phytoplankton of Lake Erie's western basin since 1971. J. Great Lakes Res. 3:72-78.
NICKEL, P.
1979. Director of Planning, Great Lakes Basin Commission. Personal Communication.
ODEN, S.
1968. The acidification of air and precipitation and its consequences on the natural environment. Swedish Nat. Sci. Res. Council, Bull. 1:1-68.
ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT
1979. Environmental policies and economic prospects for the 1980's. Environment Committee, Meeting at Ministerial Level. Paris, April 11, 1979. ENV/MIN (79)5:47.
ORFORD, M.
1968. Early exploration of Lake Erie and Lake Huron. Inland Seas 24(4):267-278.
OSBORN, J. F., and C. H. ALLMAN
1976. Instream flow needs. Amer. Fish. Soc., Bethesda, Maryland. Vols. 1 551 pp. and 2 657 pp.
OWEN, R. M.
1977. An assessment of the environmental impact of mining on the continental shelf. J. Marine Mining, 1:85-102.
PAZIK, G.
1979. But don't go near the water. Fishing Facts Magazine, Menomonee Falls, Wisc. March 1979 issue.
PEACH, P. A.
1969. The challenge of the Great Lakes. Pages l-16 in D. V. Anderson, ed. The Great Lakes as an environment. Great Lakes Inst. Rep. PR 39, Univ. Toronto, Toronto.
PEARCE, D. W.
1976. Environmental economics. Longmans, London. 202 pp.

PEET, S. E.
1978. The long lake diversion. M.A. thesis, Dept. of Geography, Univ. Waterloo, Waterloo, Ont. 271 pp.
PERKINSON, D.
1979. Hazardous materials transportation seminar: a summary. Great Lakes Basin Comm., Great Lakes Communicator. 9(4):4–5.
PESKIN, H. M., and E. P. SESKIN, eds.
1975. Cost-benefit analysis and water pollution policy. The Urban Inst., Washington, D.C. 320 pp.
PHILLIPS, D. W., and E. VEINOT
1977. A statistical analysis of Great Lakes Conferences from 1959 to 1975. J. Great Lakes Res. 3: 169-176.
REGIER, H. A.
1979. An ecosystem perspective for Great Lakes rehabilitation. Pages 73-89 *in* Helen E. Parson, ed. Proc. 1978 Seminar Ser. Geographical Inter-University Resource Management Seminar, Dept. Geography, Wilfred Laurier University Waterloo, Ont. Vol. 9.
REGIER, H. A., and V. C. APPLEGATE
1972. Historical review of the management approach to exploitation and introduction in SCOL lakes. J. Fish. Res. Board Can. 29:683-692.
REGIER, H. A., and K. H. LOFTUS
1972. Effects of fisheries exploitation on salmonid communities in oligotrophic lakes. J. Fish. Res. Board Can. 29:959–968.
RICHARDS, T. L.
1969. The Great Lakes and the weather. Pages 51-72 *in* D. V. Anderson, ed. The Great Lakes as an environment. Great Lakes Inst. Rep. PR 39, Univ. Toronto.
RICHARDSON, A. H.
1944. A Report on the Ganaraska watershed. Ontario Dept. Planning and Development, Toronto. 253 pp.
ROBBINS, J. A, and D. N. EDGINGTON
1973. The use of natural and fallout radionucleides to measure recent sedimentation rates in southern Lake Michigan using PB-210 and Cs-137. Geochim. Cosmochim. Acta. 39:285.
ROBERTSON, I., and C. BLAKESLEE
1948. Mollusca of the Niagara Frontier Region. Buffalo Soc. Nat. Sci. 19(3):
ROWBOTTOM, R.
1977. Social analysis: a collaborative method of gaining usable scientific knowledge of social institutions. Heinemann, London. 178 pp.
ROYSTON, M. G.
1979. Responsibility of industry towards the environment. The Conoco Lecture, May 21, 1979. London.
RYBICKI, R. W.
1973. A summary of the salmonid program (1969-1971). Pages l-17 *in* Michigan's Great Lakes trout and salmon fishery 1969-72. Michigan Dept. Natural Resources, Lansing, Mich.
RYDER, R. A., and L. JOHNSON
1972. The future of salmonid communities in North American oligotrophic lakes. J. Fish. Res. Board Can. 29:941-949.
SAVAGE, D. T., M. BURKE, J. D. COOPE, T. D. BUCHESNEAU, D. F. WIHRY and J. A. WILSON
1974. Economics of environmental improvement. Houghton-Mifflin, Boston 210 pp.
SCHINDLER, D. W., and E. J. FEE
1974. Experimental lakes area, whole-lake experiments in eutrophication. J. Fish. Res. Board Can. 31:937-953.
SCHNAIBERG, A.
1977. Obstacles to environmental research by scientists and technologists: a social structural analysis. Social Problems 24(5):500–520.

SCHNEIDER, J. C., and J. H. LEACH
1977. Walleye *(Stizostedion vitreum vitreum)* fluctuations in the Great Lakes and possible causes. J. Fish. Res. Board Can. 34: 18781889.
SCHOFIELD, C. L.
1976. Acid precipitation: effects on fish. Ambio 5:228-230.
SEMCOG
1978. Water quality management plan for southeastern Michigan. Southeastern Michigan Council of Governments, Detroit. 142 pp.
1979. The impacts of development of wetlands on water quality. Staff Background Paper, Southeastern Michigan Council of Governments, Detroit. 111 pp.
SEPPANEN, P.
1973. Limnological principles and possibilities with lake restoration. (English summary). Vesihallitus-Nat'l. Board of Waters, Finland. 174 pp.
SHAPIRO, J.
1975. Biomanipulation - an ecosystem approach to lake restoration. Univ. Minn. Limnol. Res. Center Contrib. 143. 32 pp.
SHAPIRO. J., V. LAMARRA, and M. LYNCH
1975. Biomanipulation: an ecosystem approach to lake restoration. Pages 85–96 *in* P. L. Brezonik, and J. L. Fox, eds. Proc. Symp. Water Quality Management Through Biological Control. Univ. Florida, Gainesville.
SIMPSON, G. D., L. W. CURTIS, and M. K. WERKLE
1968. The Cuyahoga River, Lake Rockwell to Lake Erie. In The Cuyahoga River Watershed. Inst. Of Limnology and Dept. of Biological Sciences, Kent State University, Ohio.
SKIMIN, W. E., E. C. POWERS, and E. A. JARECKI
1978. An evaluation of alternatives and costs for nonpoint source controls in the United States Great Lakes Basin. Tech. Rep. to the Int. Joint Comm.
SMITH, S. H.
1964. Status of the deepwater cisco population of Lake Michigan. Trans. Amer. Fish. Soc. 93: 155-163.
1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Board Can. 25:667–693.
1970. Trends in fishery management of the Great Lakes. In A Century of Fishes in North America. Amer. Fish. Soc. Spec. Pub. 7: 107-I 14.
SONZOGNI, W. C.
1979. Summary of results of 1979 workshop on scientific basis for dealing with chemical toxic substances in the Great Lakes. Great Lakes Basin Comm. (mimeo).
SONZOGNI, W. C., T. J. MONTEITH, and T. M. HEIDTKE
1979. Proposed Great Lakes phosphorus target loads-a synopsis and some perspectives. Great Lakes Environmental Planning Study (GLEPS). Great Lakes Basin Comm. 9 pp. (mimeo).
SPANGLER. G. R., N. R. PAYNE, J. E. THORPE, J. M. BYRNE. H. A. REGIER. and W. J. CHRISTIE
1977. Responses of percids to exploitation. J. Fish. Res. Board Can. 34:-1983-1988.
SPARLING, J., and D. BARR., eds.
1979. Why wetlands. Ontario Naturalist 19(2): 1-51.
SPOF
1975. Preliminary catalogue of programs and legislation, strategic planning for Ontario fisheries. Second Report. Ont. Min. Natural Resources, Toronto. (mimeo). Final report available: Second report of federal-provincial strategic planning of Ontario fisheries catalogue of programs and legislation. March 1976. OMNR, Toronto. 105 pp.
STEVENSON, A. L., and W. S. BENNINGHOFF
1969. Late post-glacial rise of Lake Erie and changes in vegetation on the Maumee Lake plain. Pages 347-350 *in* Proc. 12th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res.

STUPART, R. F.
1896. Rainfall and lake levels. Trans. Can. Inst. 5(1):121-127.
SWANSON, E. R.
1978. Economic evaluation of soil erosion: productivity losses and off-site damages. Pages 53-74 in the economic impact of section 208 planning on agriculture. Great Plains Agric. Council Publ. No. 86. Univ. Nebraska Dept. Agric. Experiment Sta., Lincoln.
TALHELM, D. R.
1979. Fisheries: dollars and cents. Water Spectrum 11(1):8-16.
TALHELM, D. R., R. C. BISHOP, K. W. COX, N. W. SMITH, D. N. STEINNES, and A. L. W. TUOMI
1979. Current estimates of Great Lakes fisheries values: 1979 status report. Accepted for distribution by Great Lakes Fishery Commision. 18 pp.
TAYLOR, C. R., and K. K. FROHBERG
1977. The welfare effects of erosion control, planning pesticides, and limiting fertilizer application in the corn belt. Amer. J. Ag. Econ. 59:25-36.
THOMAS, M. K.
1968. Some notes on the climatic history of the Great Lakes region. Proc. Entom. Soc. Ont. 99:21-31.
THWAITES, R. G., ed.
1959. The Jesuit relations and allied documents Pagent Book Co., New York, 71 vol. + 2 vol. index.
TILTON, D. L., R. H. KADLEC and R. R. SCHWEGLE
1978. The ecology and values of Michigan's coastal wetlands *in* coastal wetlands value study in Michigan phase II. U.S. Fish & Wildlife Service, Region III, Twin Cities, Minn. 98 pp.
TODY, W. H., and H. A. TANNER
1966. Coho salmon for the Great Lakes. Michigan Dept. Conservation Fish. Mgmt. Rep. 1 38 pp.
TRIST, E.
1977. Collaboration in work settings: a personal perspective. J. Appl. Behav. Sci. 13:268-278.
U.S. ARMY CORPS OF ENGINEERS
1974. Final environmental statement, confined disposal facility at Pointe Mouillee for Detroit and Rouge Rivers. Detroit District, Detroit, MI. 256 pp.
U.S. ARMY ENGINEER DISTRICT, DETROIT CORPS OF ENGINEERS
1979. Survey study for Great Lakes and St. Lawrence Seaway navigation season extension. Draft main report and environmental impact statement. iv + 175 + 129.
U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
1965. Report on pollution of Lake Erie and its tributaries. Washington, D.C. 100 pp.
U.S. DEPARTMENT OF INTERIOR
1967. Fish and wildlife as related to water quality of the Lake Erie basin. U.S. Fish & Wildlife Service, Washington, D.C. 170 pp.
U.S. ENVIRONMENTAL PROTECTION AGENCY
1973. The economics of clean water. U.S. Govt. Printing Office, Washington, D.C. 120 pp.
U.S. HOUSE OF REPRESENTATIVES
1973. Hearings before the Sub-Committee on Inter-American Affairs. Pages 634-713 *in* Hearings before the Committee on Foreign Affairs, 93rd Congress. Washington, D.C.
U.S. WATER RESOURCES COUNCIL
1977. Great Lakes basin region summary report for the 1975 national assessment of water and related land resources. Great Lake Basin Comm. 171 pp.
UTILITY WATER ACT GROUP
1978. Thermal discharge reports submitted to the U.S. Environmental Protection

Agency. (in Part 2), Biological effects of once-through cooling. (in Part 1), Great Lakes basin and connecting water bodies. (Vol. 5). Available from P.O. Box 1535, Richmond, VA 23212.
VALLENTYNE, J. R.
1974. The algal bowl. Canada Fisheries and Marine Serv. Misc. Spec. Publ. No. 22. 185 pp.
1979. Personal communication. Canada Centre for Inland Waters, Burlington, Ont.
VAN OOSTEN, J.
1948. Turbidity as a factor in the decline of Great Lakes fishes with special reference to Lake Erie. Trans. Am. Fish. Soc. 75:281–322.
VAN OOSTEN, J., R. HILE, and F. W. JOBES
1946. The whitefish fishery of Lakes Huron and Michigan with special reference to the deep trapnet fishery. Fish. Bull. USFWS 50:297-394.
VAN WINKLE, W., ed.
1977. Assessing the effects of power-plant induced mortality on fish populations. Pergamon Press, New York 380 pp.
VEITH, G.
1975. Baseline concentrations of polychlorinated biphenyls in Lake Michigan fish, 1971. Pest. Mon. J. 9:21.
VERDUIN, J.
1969. Man's influence on Lake Erie. Ohio J. of Sci. 69(2):65-70.
VOLLENWEIDER, R. A.
1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication factors. OECD, Paris. OECD Tech. Rep. DAS/DSI/68. 182 pp.
VOLLENWEIDER, R. A., M. MUNAWAR, and P. STADLEMANN
1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J. Fish Res. Board Can. 31:739–762.
WADE, J. C., and E. 0. HEADY
1977. Controlling nonpoint sediment sources with cropland management: A national economic assessment. Am. J. Ag. Econ. 59:13-14.
WALKER, D. J.
1977. An economic analysis of alternative environmental and resource policies for controlling soil loss and sedimentation from agriculture. Ph.D. thesis, Department of Ag. Econ., Iowa State University, Ames.
WARWICK, W. F.
1975. The impact of man on the Bay of Quinte, Lake Ontario, as shown by the subfossil chironomid succession (Chironomidae diptera). Verh. Internat. Verein. Limnol. 19:3134-3141.
WEININGER, D.
1978. Accumulation of PCBs by lake trout in Lake Michigan. Ph.D. thesis, (Water Chemistry), Univ. Wisconsin-Madison. 232 pp.
WELLS, L.
1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnol. Oceanogr. 15:556-565.
WELLS, L., and A. McLAIN
1972. Lake Michigan: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29:889-898.
WESTINGHOUSE ELECTRICAL CORPORATION
1971. Performance and environmental aspects of cooling towers. Westinghouse Electrical Corp. Environ. Systems Dept., Pittsburgh, Pennsylvania. 140 pp.
WHILLANS, T. H.
1977. Fish community transformation in three bays within the lower Great Lakes. M.Sc. thesis, Department of Geography, University of Toronto, 328 pp.
1978. Records of fish from archeological material in the Canadian Great Lakes region. Univ. Toronto Inst. Environ. Studies (unpubl.). 23 pp.

WHITE, G. B.
1978. The economic implications of clean streams legislation for selected commercial dairy farms in Pennsylvania. Ph.D. thesis, Department of Agricultural Economics, Penn. State University, College Station, Pennsylvania. 253 pp.

WINDOM, H. L.
1972. Environmental aspects of dredging in estuaries. J. Am. Soc. Civil Eng. 98, No. WW4:475-487.

WRIGHT, R. F., T. DALE, A. HENRIKSEN, G. R. HENDREY, E. T. GJESSING, M. JOHANNESSEN, C. LYSHOLM and E. STRØREN.
Regional surveys of small Norwegian lakes. Intern. rapport IR33/77. SNSF-project. Oslo.

YAFFEE, S. L.
1976. Simulation and interaction of regional systems. Oak Ridge National Laboratory, Oakridge, Tennessee. 37 pp. and appendices.

GREAT LAKES FISHERY COMMISSION

TECHNICAL REPORT SERIES

No. 1. Use of 3-trifluormethyl-4-nitrophenol as a selective sea lamprey larvicide, *by Vernon C. Applegate, John H. Howell, James W. Moffett, B. G. H. Johnson,* and *Manning A. Smith.* May 1961. 35 pp.

No. 2. Fishery statistical districts of the Great Lakes, *by Stanford H. Smith, Howard J. Buettner,* and *Ralph Hile.* September 1961. 24 pp.

No. 3. Commercial fish production in the Great Lakes 1867-1960, *by Norman S. Baldwin* and *Robert W. Saalfeld.* July 1962. 166 pp.
Supplement covering the years 1961-68. 1970. 90 pp.

No. 4. Estimation of the brook and sea lamprey ammocete populations of three streams, *by Bernard R. Smith* and *Alberton L. McLain.* September 1962. pages 1-18.
A photoelectric amplifier as a dye detector, *by Wesley J. Ebel.* September 1962. pages 19-26.

No. 5. Collection and analysis of commercial fishery statistics in the Great Lakes, *by Ralph Hile.* December 1962. 31 pp.

No. 6. Limnological survey of Lake Erie 1959 and 1960, *by Alfred M. Beeton.* November 1963. 32 pp.

No. 7. The use of alkalinity and conductivity measurements to estimate 'concentrations of 3-trifluormethyl-4-nitrophenol required for treating lamprey streams, *by Richard K. Kanayama.* November 1963. 10 pp.

No. 8. Synergism of 5,2'-dichloro-4'-nitro-salicylanilide and 3-trifluormethyl-4-nitrophenol in a selective lamprey larvicide, *by John H. Howell, Everett L. King, Jr., Allen J. Smith,* and *Lee H. Hanson.* May 1964. 21 pp.

No. 9. Detection and measurement of organic lampricide residues, *by Stacy L. Daniels, Lloyd L. Kempe, Thomas J. Billy,* and *Alfred M. Beeton.* 1965. 18 pp.

No. 10. Experimental control of sea lampreys with electricity on the south shore of Lake Superior, 1953-60, *by Alberton L. McLain, Bernard R. Smith,* and *Harry H. Moore.* 1965. 48 pp.

No. 11. The relation between molecular structure and biological activity among mono-nitrophenols containing halogens, *by Vernon C. Applegate, B. G. H. Johnson,* and *Manning A. Smith.* December 1966. pages 1-19.
Substituted nitrosalicylanilides: A new class of selectively toxic sea lamprey larvicides, *by Roland J. Starkey* and *John H. Howell,* December 1966. pages 21-29.

No. 12. Physical limnology of Saginaw Bay, Lake Huron, *by Alfred M. Beeton, Stanford H. Smith,* and *Frank F. Hooper.* September 1967. 56 pp.

No. 13. Population characteristics and physical condition of alewives, *Alosa pseudoharengus,* in a massive dieoff in Lake Michigan, 1967, *by Edward H. Brown, Jr.* December 1968. 13 pp.

No. 14. Limnological survey of Lake Ontario, 1964 (five papers), *by Herbert E. Allen, Jerry F. Reinwand, Roann E. Ogawa, Jar1 K. Hiltunen, and LaRue Wells.* April 1969. 59 pp.

No. 15. The ecology and management of the walleye in western Lake Erie, *by Henry A. Regier, Vernon C. Applegate* and *Richard A. Ryder,* in collaboration with *Jerry V. Manz, Robert G. Ferguson, Harry D. Van Meter;* and *David R. Wolfert.* May 1969. 101 pp.

No. 16. Biology of larval sea lampreys (Petromyzon *marinus]* of the 1960 year class, isolated in the Big Garlic River, Michigan, 1960-65, by P&rick 1. *Manion* and *Alberton L. McLain.* October 1971. 35 pp.

No. 17. New parasite records for Lake Erie fish, *by Alex* 0. *Dechtiar.* April 1972. 20 pp.

No. 18. Microbial degradation of the lamprey larvicide 3-trifluoromethyl-4-nitrophenol in sediment-water systems, *by Lloyd L. Kempe.* January 1973. 16 pp.

No. 19. Lake Superior-A case history of the lake and its fisheries, *by A. H. Lawrie* and *Jerold F. Rahrer.* January 1973. 69 pp.

No. 20. Lake Michigan-Man's effects on native fish stocks and other biota, *by LaRue Wells* and *Alberton L. McLain.* January 1973. 55 pp.

No. 21. Lake Huron-The ecology of the fish community and man's effects on it, *by A. H. Berst* and *G. R. Spangler.* January 1973. 41 pp.

No. 22. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie, *by W. L. Hartman.* April 1973. 43 pp.

No. 23. A review of the changes in the fish species composition of Lake Ontario, *by W. J. Christie.* January 1973. 65 pp.

No. 24. Lake Opeongo-The ecology of the fish community and of man's effects on it, *by N. V. Martin* and *F. E. J. Fry.* March 1973. 34 pp.

No. 25. Some impacts of man on Kootenay Lake and its salmonoids, *by T. G. Northcote.* April 1973. 45 pp.

No. 26. Control of the sea lamprey *(Petromyzon marinus)* in Lake Superior, 1953-70, *by Bernard R. Smith, J. James Tibbles,* and *B. G. H. Johnson.* March 1974. 60 pp.

No. 27. Movement and recapture of parasitic-phase sea lampreys *(Petromyzon marinus)* tagged in the St. Marys River and Lakes Huron and Michigan, 196367, *by Harry H. Moore, Frederick H. Dahl,* and *Aarne K. Lamsa.* July 1974. 19 pp.

No. 28. Changes In the lake trout population of southern Lake Superior in relation to the fishery, the sea lamprey, and stocking, 1950-70, *by Richard L. Pycha* and *George R. King.* July 1975. 34 pp.

No. 29. Chemosterilization of the sea lamprey *(Petromyzon* marinus), *by Lee H. Hanson* and *Patrick J. Manion.* July 1978. 15 pp.

No. 30, Biology of larval and metamorphosing sea lampreys *(Petromyzon marinus)* of the 1960 year class in the Big Garlic River, Michigan, Part II, *1966-72, by Patrick J. Manion* and *Bernard R. Smith.* October 1978. 35 pp.

No. 31. Walleye stocks in the Great Lakes, 1800-1975: fluctuations and possible causes, *by J. C. Schneider* and *J. H. Leach.* February 1979. 51 pp.

No. 32. Modeling the western Lake Erie walleye population: a feasibility study, *by B. J. Shuter, J. F. Koonce,* and *H. A.* Regier. April 1979. 40 pp.

No. 33. Distribution and ecology of lampreys in the Lower Peninsula of Michigan, 1957-*75, by Robert H. Morman.* April 1979. 59 pp.

No. 34. Effects of granular 2', 5-dichloro-4'-nitrosalicylanilide (Bayer 73) on benthic macroinvertebrates in a lake environment. *bv Philip A. Gilderhus.* May 1979. Pages 1-5.
Efficacy of antimycin for control of larval sea lampreys *(Petromyzon marinus)* in lentic habitats, *by Philip A. Gilderhus. May 1979.* Pages 6-17.

No. 35. Variations in growth, age at transformation, and sex ratio of sea lampreys reestablished; in chemically treated tributaries of the upper Great Lakes, *by Harold A. Purvis.* May 1979. 36 pp.

No. 36. Annotated list of the fishes of the Lake Ontario watershed, *by E.* J. Crossman and *Harry D. Van Meter.* December 1979. 25 pp.