GREEN BAY IN THE FUTURE—
A REHABILITATIVE PROSPECTUS

Great Lakes Fishery Commission

TECHNICAL REPORT No. 38

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.

GREEN BAY IN THE FUTURE - A REHABILITATIVE PROSPECTUS

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INTRODUCTION AND SUMMARY

THE PROBLEM: PIECEMEAL APPROACH TO ECOSYSTEM REHABILITATION

One of the focal points for the "Great Environmental Movement" of the late 1960s and early 1970s was the deteriorating water quality of the Great Lakes. Lake Erie was "dying." Public concern mushroomed and soon was reflected in numerous legislative and administrative actions.

Two binational bodies manage transboundary concerns in the Great Lakes. The International Joint Commission (IJC), established in 1912 under the Boundary Waters Treaty of 1909, immediately began to investigate pollution in the lakes and other joint problems. The Great Lakes Fishery Commission (GLFC) was established under the 1955 Convention on Great Lakes Fisheries to control the pestilent sea lamprey (Petromyzon marinus) and to coordinate rehabilitation of many devastated fish stocks of common concern. Subsequently both bodies greatly increased their involvement, investigating the problems and possible solutions.

The 1972 Great Lakes Water Quality Agreement strongly committed the United States and Canada to reduce pollution entering the lakes through a program of controls. Yet the conditions over much of the Great Lakes continued to deteriorate or failed to improve. The treaty called for a 5th-yr review. Widening dissatisfaction was expressed with the prevailing approach to rehabilitation, which established an ever-lengthening list of specific water quality objectives agreed to on an individual parameter by parameter basis. Scientists found that various mixes of pollutants, each present in "acceptable" amounts under the discharge limit approach, may still produce unacceptable results (Francis et al. 1979). As they understood the causes and consequences better, they began to argue that a more holistic approach was necessary: one that focused on the condition of the ecosystem rather than on individual parameters.

A new agreement was drawn up, the 1978 Water Quality Agreement, continuing the prevailing approach of specific parameter limits, but focusing attention on the water quality of the entire Great Lakes basin ecosystem. By this time several initiatives had begun to explore the idea of an ecosystem approach to rehabilitation (Francis et al. 1979). In 1977 the IJC and the GLFC agreed to work more closely together, and the GLFC agreed to investigate the state of the art and the feasibility of utilizing an ecosystem approach in rehabilitating the Great Lakes. This paper reports some results of that effort.

In our view, the tremendously complex Great Lakes ecosystem involved so may physical, biological, social, and institutional dimensions that no one could completely comprehend it, and no present organization could effectively manage or be responsible for rehabilitating the entire ecosystem. We concluded that there could be important gaps in knowledge and/or management responsibilities, and that it was important to develop a better approach.

DEVELOPING AN ECOSYSTEM APPROACH

In 1979, after a preliminary study of the feasibility of rehabilitating Great Lakes ecosystems (Francis et al. 1979), the GLFC funded a case study of Green Bay, Lake Michigan. The Commission recognized that ecological rehabilitation of the Great Lakes should be initiated first for smaller ecosystems such as bays and harbors and tailored to the particular conditions and stresses impacting particular areas.

The case study of Green Bay, facilitated by the University of Wisconsin Sea Grant Institute, examined various approaches to resource rehabilitation planning and management. Our efforts have created a new "ecosystem approach" to understanding rehabilitation: a tactical, normative planning capability focused on major aquatic ecosystems, their user groups and the institutions that affect both. The approach is based on our concepts that first, all user-related stresses can be classified in a comprehensive taxonomy and second, information from the physical, biological, and social sciences-particularly economics, ecology, and political science-can be organized to characterize the functional relationships between and among users and ecosystem stresses.

Methodology incorporates the process-oriented inquiry techniques of "general systems analysis," so it offers fair and balanced opportunities for both holistic and reductionistic approaches. It operates as a kind of Delphi approach by (1) asking scientists from various disciplines and individuals from various user groups to classify stresses and characterize functional relationships, (2) reinforcing these judgments and related questions through literature searching and other research, and then (3) asking another group of scientists and users to review and revise the original conclusions. Our approach seems consistent with the principles of "adaptive management" (Holling 1978), in which management proceeds through progressive trial-and-error stages while maintaining flexibility.

Three successive workshops were held to assess the most critical stresses affecting the Green Bay ecosystem and to define technical, socioeconomic, and institutional aspects of rehabilitation. Analysis of these factors, based upon matrix construction and graph theory, indicated that for Green Bay the most significant stresses involved nutrients, suspended solids and sediments, toxic substances and the fishery.

THE GREEN BAY PLAN

The outcome of the planning effort is an ecosystem-oriented management plan that recommends specific strategies for dealing with critical biological and physical stresses affecting the bay. The plan addresses marginal costs and benefits of rehabilitation strategies and identifies the need for institutional arrangements for implementing the plan within the existing local, state, and federal frameworks.

Management priorities for the rehabilitation plan include: reducing nutrients and suspended solids generated in upstream urban and rural areas, minimizing wind stress and resuspension of bottom sediments, curtailing carp populations, and decreasing toxic substances in the ecosystem. The overall results of rehabilitation would be a significant increase in water quality and a subsequent improvement in both the fishery and the recreational potential of the bay.

As almost no estimates of specific dollar values for rehabilitative strategies are available, it is difficult to assess the benefits and costs of various options. However, subjective estimates can be derived from public values expressed by workshop participants, who represented a variety of public interests and interdisciplinary areas of technical expertise. The stresses they judged to be most critical for Green Bay reflect the broader public perspective of desirable uses of the bay and may implicitly yield the only available estimates of the value of rehabilitation.

Any rehabilitation strategy devised must consider the institutional arrangements necessary to implement management plans. A complex array of political units have authority over the waters of Green Bay and related land resources. Many of these agencies have a single focus to their activities, whereas others administer multifunctional aspects of environmental management; in some cases legal responsibilities overlap. To simplify these complex interactions and avoid potential interagency conflicts, a lead agency could be designated to act as the central, coordinating group responsible for administering rehabilitation management policies.

The link between research, planning, and management must be strengthened if rehabilitative change is to occur. Formal linkages (i.e. review and comment processes) must be augmented, perhaps through continued workshop or task force efforts. The interpersonal relationships that are fostered through informal coordination form a network of concerned individuals with a common goal: ecosystem rehabilitation.

The process of designing a rehabilitation plan, the strategies recommended, and the suggestions outlined for translating the plan into policy and administration have broad implications for continuing efforts to rehabilitate Great Lakes ecosystems. We recommend that this report be used in the further development of the Strategic Great Lakes Fishery Management Plan, sponsored by the GLFC, and that it be distributed in appropriately designed technical or nontechnical formats.

GREEN BAY: A CASE STUDY

Green Bay can be characterized as a long, shallow extension of northwestern Lake Michigan (Fig. 1). Morphometric statistics include: a length of 193 km (120 mi) along a medial track running NE from the mouth of the Fox River to the head of Big Bay de Noc; a mean width of 22 km (14 mi); a mean depth of 15.8 m (52 ft); a water surface area of 4520 km” (1640 mi^2); and a volume of about 67 km^2 (16 mi^3) (Mortimer, 1978).

The Green Bay watershed drains about 40000 km^2 (15675 mi^2) of land surface in 24 counties of both Wisconsin and Michigan, or about one-third of the total Lake Michigan drainage basin (Bertrand et al. 1976). Although 14 rivers and numerous tributaries drain into Green Bay, the Wolf-Fox River system contributes the largest volume of water (an estimated mean of 118 ms^{-1}) (Mot-timer 1978) and most of the suspended and dissolved pollutants entering the bay (Bertrand et al. 1976). About one-third of the total watershed is forested whereas much of the rest is intensively farmed or occupied by urban areas. In addition, the Fox River valley is heavily industrialized and contains the largest concentration of pulp and paper mills in the world.

The lower bay and Fox River have been recognized for many years as an extremely polluted water system (Bertrand et al. 1976). Urban development, industry, farming, logging, and other human activities have contributed to complex water quality problems; high water levels in the Great Lakes system and human encroachment have eliminated wetland areas; waterfowl populations and hunting activities have declined for more than a decade; and the commercial fishery in the lower bay has been reduced to perch, while the sport fishery nearly disappeared for a time.

GREEN BAY’S RESOURCES: THE UNLIMITED PERSPECTIVE

During the past 150 yr resources of the Green Bay ecosystem have supported a wide range of human enterprises, including agriculture, fishing, logging, and industrial development. Settlers and immigrants first came to northeastern Wisconsin to develop expanses of rich forest lands, harvest the bountiful fishery and wildlife resources, and transport goods via extensive waterways. The frontier ethic, based upon unlimited availability of natural resources, dominated the times (Leopold 1949). Early settlers and industrial developers used resources at a rapid rate, often ignoring the impact of their particular activity upon other resources. Ultimately the ecosystem was degraded at a rate greater than its ability to restore itself.

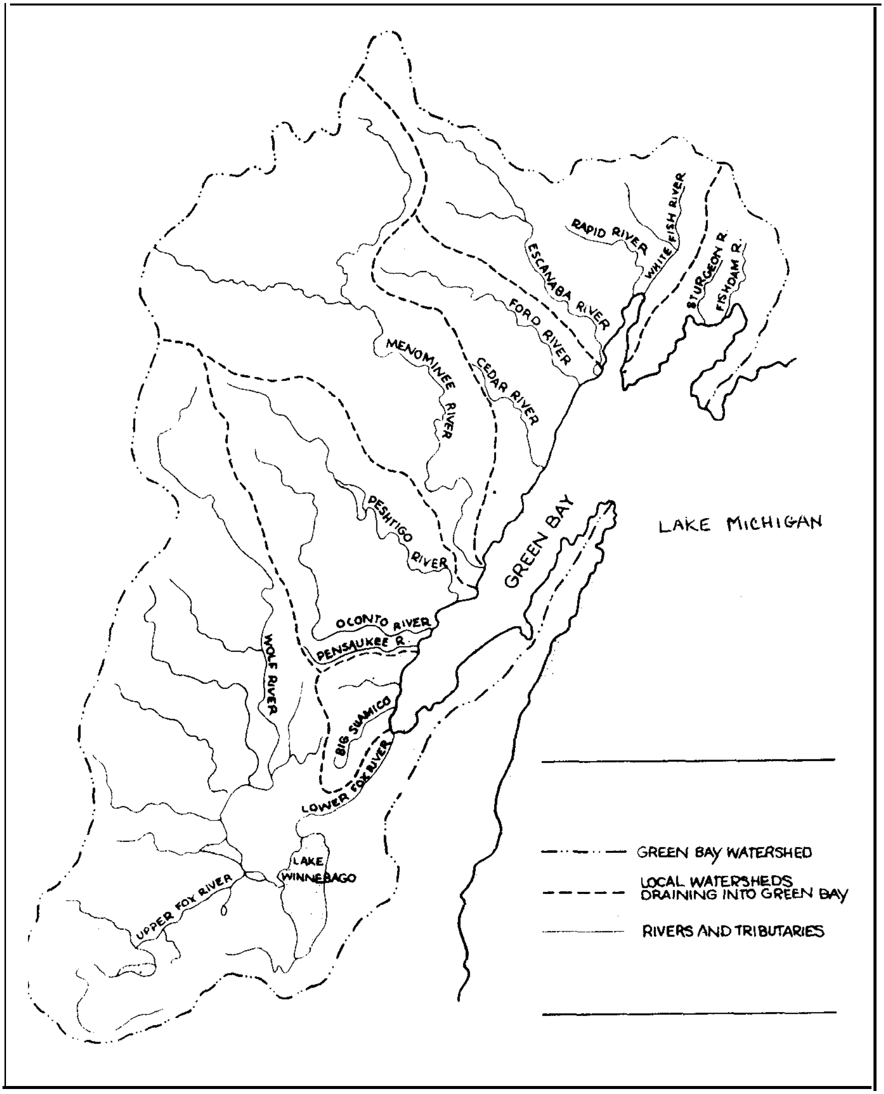


FIG. 1. River drainage basins of the Green Bay watershed.

A HISTORYOF USE: ELEMENTS OF ECOSYSTEM DEGRADATION

Buy wetlands-It is estimated that during the 1840s, 15 mi^2 of coastal marshes and 72 mi^2 of coastal swamps existed along Green Bay's west shore (Bosley 1978). Within the past century, however, 60% of the coastal marshes have been converted to agricultural land, filled with dredge spoils, or invaded by cottage settlements. Swamp forests of tamarack, alder, white cedar, and black ash have been harvested for timber; almost 60 mi^2 of these forests have disappeared altogether (Bosley 1978). Today approximately only 6 mi^2 of marsh and 12 mi^2 of swamp remain at high water levels.

The loss of these wetlands is permanent. Roth (1898) and Wells (1968) reported that swamps in the west shore area rested on sandy soil overlain with water-holding peat. After stands of timber were harvested, the peat was burned, and the underlying sandy soil could no longer supply enough moisture to support species characteristic to northern swamp forests. Original species were replaced by trees adapted to drier conditions.

An accurate assessment of the effect these wetland losses have had upon the Green Bay ecosystem can probably never be made. However, wetland losses may have significantly influenced the decline of Green Bay and Lake Michigan fisheries. Not until recently has the public begun to understand the special value of these wetland areas.

Logging and agriculture-Severe soil erosion, induced by logging and farming practices, has had a substantial impact upon the bay. Early farmers cleared land by girdling trees, then disposed of the unwanted timber in any way possible. Surface runoff from vast tracts of cleared agricultural lands, seasonally exposed to erosion, increased sediment loading of waters emptying into the bay. Additional land surfaces were exposed to erosion by timber clear-cutting and spring log runs. Changes in stream sediment loads and water temperatures had direct effects upon the bay's water quality and the fishery. Although some reforestation and soil conservation practices were initiated around the turn of the century, it was not until the Depression of the 30s that serious efforts were made to reduce soil erosion.

Industrial development-After 1900, pulp and paper mills flourished along the lower Fox River. As the demand for paper products increased across the nation, rapid expansion of the industry followed. Industrial waste discharge into the river kept pace with the expansion, until by 1970 -500000 lb of BOD per day were being released into downstream receiving waters. Inadequate regulatory and/or economic incentives for change have contributed to the degrading impact industrial practices have had upon the waters of the ecosystem.

Bay fishery - For over a century, the highly productive waters of Green Bay have supported an intense commercial fishery, in spite of the successive depletion of desirable species. Early fishermen took advantage of phenomenal quantities of easily speared or netted pike, whitefish, herring, and sturgeon that inhabited tributary streams (Lloyd 1966). In addition to the intense harvest of some species, spawning and nursery grounds have been reduced as streams were dammed and wetlands destroyed.

To compound the problems of the fishery, exotic species have been accidentally or purposefully introduced to regional waters. Although the sea lamprey has received the most publicity as a cause of Great Lakes fish stock problems (Christie 1974), the decline of stocks cannot be attributed to any one factor (Francis et al. 1979). Exotic fish, such as rainbow smelt, alewife, and carp also share the blame for stock losses (Smith 1970).

Water quality began to improve around 1970 when new waste treatment plants became operable. Severe anaerobic conditions, previously common, have not been present since the mid-1970s. Since then, dissolved oxygen content in the lower Fox River and bay has improved steadily and the sport fishery is gradually being reestablished.

A new threat to the fishery is the presence of a wide spectrum of microcontaminants in the lower bay (Sullivan and Deltino 1982). Chlorinated hydrocarbons, including PCBs and others, are extremely stable in the environment and can be biomagnified by fish. Allowable levels of PCBs in fish used for human consumption are set at 5 ppm by the Food and Drug Administration, but some lake trout in Green Bay have been found to contain levels as high as 15-35 ppm (Veith 1975; Weininger 1978). As a result, sport fishermen have been advised to change fishing locations and reduce the frequency of fish consumption, whereas the commercial fishery has suffered financial hardships due to changes in harvest patterns. The long-term effects of microcontaminants, such as chlorophenols and trace metals, are presently unknown. These substances may pose an increasingly serious problem for the fishery.

Breakdown of a system-Clearly the decline of the fishery reflects degradation of the ecosystem over time. The present condition of the fishery represents the collective effects of stresses, such as municipal and industrial waste loading, discharge of microcontaminants, increased sediment and nutrient loading due to soil erosion, loss of wetland and riverine habitat, overfishing and the introduction of exotic species. Because of its keen sensitivity to water quality, the fishery can be considered as the "barometer" of the ecosystem. Scientists, resource managers, and users are becoming increasingly aware of the difficulty of rehabilitating the fishery without also rehabilitating the ecosystem.

RESOURCE MANAGEMENT: THE NEED FOR AN ECOSYSTEM APPROACH

Pioneers in ecology recognized the intricate network of interactions within ecosystems and the necessity for appraising the impacts of human activities upon natural systems as a whole (White 1980). The emergence of ecosystem approaches to resource management stems not only from a need to restore or retain ecosystem integrity, but also from a recognition of the failure of single-factor management strategies. Single species management of the Great Lakes has not yet led to a self-sustained and diverse fishery. Similarly, an emphasis on species management of harvestable waterfowl has not led to increased numbers and diversity of wetland avifauna; nor have single-factor approaches to water quality necessarily led to more fishable and swimmable waters.

State of the art-Management of complex ecosystems is at present an emerging body of knowledge, but Lee et al. (1982) note that differing versions of ecosystem approaches usually share the following aspects:

- a primary focus on ecological phenomena;
- a perception of the ecosystem as somewhat self-regulating and limited in recovery capability; and
- a willingness to adapt both reductionist (i.e. single factor) and holistic techniques in a flexible approach to problems.

Effective ecosystem management further requires that research be integrated with environmental planning and multiple-use policy formulation. Environmental planning provides a means of allocating ecosystem resources, taking into consideration both natural system capabilities and socioeconomic contingencies. Ideally, policy formulation for multiple-use should reflect public values as well as natural system capabilities.

ECOSYSTEM RESEARCH AND PLANNING: OPPORTUNITY AND CHALLENGE

After 1965 and the progressive enactment of state and federal water quality standards, Green Bay received the increased attention of environmental agencies. In 1966, for example, the Federal Water Pollution Control Administration published a comprehensive water pollution control program for the bay. This program was an important step, but was based upon meager data because few studies had been conducted before 1966.

By the early 1970s, however, the Green Bay ecosystem had been extensively studied, notably by the Wisconsin Sea Grant Institute and the Wisconsin Department of Natural Resources (WIDNR). A 1974 WIDNR report (Epstein et al. 1974) revealed trends in water quality, aquatic life, and waste loadings of the bay. While the review and synthesis of existing data did not permit the authors to portray a definitive model of the structure and function of the ecosystem, studies of nutrient loading provided the following conclusions:

- phosphorus in the form of PO_4 (orthophosphate) appears to be the limiting nutrient for algal growth in Green Bay;
- periodic increases in soluble phosphate concentration promote the growth of nitrogen-fixing algae;
- Fox River is the major source of phosphorus enrichment of the bay;

- extremely high concentrations of soluble phosphate in the lower bay can be correlated with heavy precipitation and subsequent increase of phosphorus in the Fox River;
- sediments in the Fox River and Green Bay are a significant source of phosphorus;
- approximately two-thirds of the total phosphorus discharged by the Fox-Wolf River is contributed by municipal and industrial waste;
- phosphorus contributed by surface runoff from nonpoint sources is a significant and measurable source; and
- total phosphorus and orthophosphorus concentration gradients in the bay are steeper south of Long Tail Point (Fig. 4, p. 26) than at more northerly points.

The report notes that few studies on mixing, dispersal, and transport of water in Green Bay had been undertaken, but from the studies that had been conducted some revealing characteristics emerge:

- wind and current patterns play the most important roles in mixing and transporting water within Green Bay;
- 50-80% by volume of water south of Long Tail Point consists of Fox River water;
- concentrations of Fox River water in the bay decrease rapidly, as shown by conductivity measurements (values > 25% are seldom observed beyond 2.5 km north of the mouth of the river);
- lakeward movement of Fox River water is generally along the east side of the bay, where it may constitute as much as 80% of the northward current;
- low transparency in the inner bay is caused by phytoplankton concentrations and by suspended solids from sediments in regions where water depths are generally < 2-3 m and sediments are subject to wind-induced turbulence; and
- estimates of flushing rates in lower Green Bay vary from 29 to 160 d.

Historical changes in the fishery, dissolved oxygen content and bottom sediments were also described in this report. The commercial fishery, for example, had experienced changes in species composition. Species available for harvest shifted from the traditional native species to exotic species of lower quality especially alewife and carp. Furthermore, bottom sediment data indicated that the bay is filling at a rate 10-100 times that associated with large bodies of water. The report concluded that many dimensions of the ecosystem required further study; **nevertheless,** the studies conducted thus far provided an important base for management alternatives.

UW Sea Grant research-From 1970 to 1975, the Wisconsin Sea Grant College conducted the "Green Bay Program" to obtain additional information about the bay and integrate ongoing research efforts. The culmination of this early program was a publication, *The Green Bay Watershed, Past/Present/Future* (Bertrand et al. 1976), which summarized research on the physical, chemical, and biological characteristics of the bay. This publication goes beyond the Epstein et al. (1974) report in that cultural, economic, and historical characteristics of the region were considered and the need for a holistic approach to management was emphasized. Examination of the existing data base was also an important aspect of this study and provided a basis for determining future research priorities.

Completion and distribution of the Epstein et al. (1974) and Bertrand et al. (1976) publications helped crystallize emerging research and management policies and stimulated further interest in the bay. A 1978 workshop sponsored by the UW Sea Grant Institute revitalized the earlier Green Bay Program and strengthened goals of researchers and managers to work towards resolution of ecosystem problems and enhancement of the bay's natural environment. A research program funded at ~$350 K per year was established and the following studies, based upon previously identified research priorities (Harris and Garsow 1978), have been undertaken:

- Biological production in Green Bay coastal marshes
- Remote sensing of the Green Bay watershed to estimate the impact of land development on the bay's water quality
- Nonpoint source pollution in Green Bay and its implication for water quality management
- Water mass structure and exchanges in Green Bay
- Physical-chemical characteristics and dynamics of Green Bay
- An assessement of selected organic pollutants in the lower Fox River/Green Bay aquatic system
- Fate of arsenic deposited in Green Bay by the Menominee River
- Persistence of pollutants in the sediments of Lake Michigan's Green Bay
- Characterizing the Green Bay pelagic food chain and the relationship between phytoplankton and fish production
- Vital statistics and population structure of age I, II, III lake whitefish in Green Bay and Wisconsin waters of Lake Michigan and of the northern Lake Michigan whitefish fishery
- dynamics of herbivore populations and first-year yellow perch in lower Green Bay
- Dynamics of sucker populations of Green Bay and adjacent waters of Lake Michigan
- Factors influencing the reestablishment of self-sustaining stocks of lake trout in Lake Michigan with special reference to Green Bay

Although these projects were carefully selected to provide an integrated research approach, it became increasingly clear that new knowledge generated by these research efforts would not necessarily lead to an ecosystem-oriented management program for the bay. Research findings, it became apparent, must be integrated with public values and public agency responsibilities. An information flow between researchers and managers must occur in order to create the interface which allows research findings to be incorporated into management alternatives. Once realistic and valid alternatives are identified, decision-makers and the general public can more readily discern the advantages and disadvantages of particular courses of action. In this way the transition from research to ecosystem management can be effectively achieved.

Recognizing the opportunity presented by ecosystem research, GLFC funded a study to develop a rehabilitation plan for the bay. The design of this plan may serve as one important first step toward the rehabilitation of Great Lakes ecosystems.

DESIGNING A PLAN: THE PROCESS

Two major ecosystems were identified by the Commission study group as areas with pressing rehabilitation needs: Green Bay (Lake Michigan) and the Bay of Quinte (Lake Ontario). In both cases many of the stress factors acting upon these ecosystems were readily identifiable and substantial research had already been carried out. The attention of scientists, resource managers and the public was actively focused on concern over deterioration of these aquatic systems.

Ecosystems by definition are diverse, dynamic systems characterized by complex interrelationships. The interaction of stresses upon a system, acting either singly or in combination, can alter ecosystems significantly. To identify critical stresses acting upon Green Bay and to determine the direction rehabilitation efforts should take, a series of workshops was planned: Green Bay I, II, and III. Members of the scientific community, resource user groups, and public agencies were invited to participate. A workshop similar to Green Bay I was held at the Bay of Quinte.

GREEN BAY I

Workshop participants met in April 1979 and began the process of testing the applicability of ecosystem-oriented rehabilitation for Green Bay. This workshop laid the foundation for a group process of investigation and evaluation and identified information needs for future workshops.

The first task was to devise a preliminary ranking of the most critical stresses acting upon the bay. Eighteen primary stresses influencing the ecosystem were listed as follows in Table 1.

TABLE I. Primary stresses affecting the Green Bay ecosystem.

1. PCBs	10. Suspended solids and sedimentation
2. Nutrient loading	11. Dams and dam removal
3. Fishing	12. Heavy metals
4. Manipulation of fish associations (stocking)	13. Shoreworks and offshore development
5. Accidental introduction and invasions of fish species	14. Petroleum wastes
6. Dredging	15. Entrainment/impingement
7. Landfill operations	16. Shipping disturbances
8. BOD loadings	17. Water level management
9. Other toxics and hazardous substances	18. Thermal modifications

The identification of stresses affecting the bay led to the construction of three scenarios that might describe how specific stresses and modification of these stresses might affect the fishery: (a) reducing the allowable PCB residues in fish by the FDA from 5 to 2 ppm; (b) decreasing overfishing and entrainment and impingement of yellow perch; and (c) removing dams to allow spawning access to rivers (Francis et al. 1979).

Participants of this first workshop developed a strong commitment to move rehabilitation efforts from the area of general concern to active application of rehabilitation strategies.

GREEN BAY II

The sources of ecosystem stress had been identified at Green Bay I; the next step was to take a more analytical approach to defining the critical elements of ecosystem rehabilitation in Green Bay. Green Bay II, held in February 1980, focused upon three aspects of rehabilitation management:

Technical Aspects

- How do the stresses affecting the Green Bay ecosystem interact with each other?
- Can clusters of closely related stresses be identified?
- How do identified stresses affect the components of the ecosystem?
- What are the technical solutions available, and are those solutions appropriate for Green Bay?

Socioeconomic Aspects

- Who are the users of the Green Bay ecosystem?
- How do stresses affect users? How do users influence stresses?
- What are the costs/benefits and risks/benefits associated with various rehabilitation options?

Institutional Aspects

- What are the responsibilities of local, state, regional, federal, and international institutions for addressing particular ecosystem stresses?
- Where do institutional arrangements facilitate rehabilitation?
- Where do institutional arrangements impede rehabilitation?

The 33 participants of Green Bay II represented a geographical cross section of the region, as well as a mixture of various disciplines and interests, and provided a broad base of technical expertise. Graduate students from the University of Wisconsin and Michigan State University, who participated, would play a role in research and development of recommendations for the rehabilitation plan.

Participants were divided into three separate working groups to develop matrices which would be used to evaluate stress interactions. A Technical group considered stress/stress relationships; an Economic group addressed stress/user interactions; and an Institutional group focused upon the institutional framework for managing stresses affecting the ecosystem.

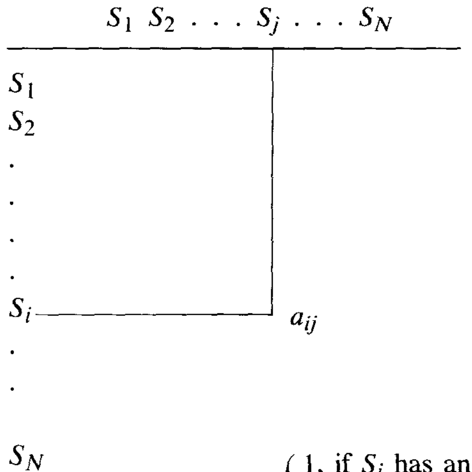
Analysis of the matrices developed during Green Bay II provided a systematic method of examining and evaluating stress interrelationships as well as providing a focus for more detailed research. Graduate seminars held at the University of Wisconsin-Madison and Michigan State University-East Lansing continued research on stresses, user groups, and institutions responsible for ecosystem management.

Matrix development and analysis-A better understanding of the dynamics of the ecosystem as a whole could be derived by analyzing relationships among the 18 identified stresses. If closely related stresses that might form a subsystem or "cluster" of stresses could be identified, rehabilitative strategies aimed at clusters of stresses, rather than individual stresses, could be developed. It was reasoned that if this first step could be accomplished in quantifying relationships among stresses, then a logical next step would be to quantify relationships between stresses and their effects.

To study the complex interrelationships of all stresses, we utilized the principles of graph theory (Roberts 1976). For example, if we treat each stress as a vertex and if stress S_i has an impact upon stress S_j, a directed arc can be drawn from vertex S_i to S_j as:

$$S_i \longrightarrow S_j$$

When each pair of stresses is evaluated in this manner, a directed graph or "digraph" can be constructed, based on the following matrix framework for the data:



$$\text{where } a_{ij} = \begin{cases} 1, & \text{if } S_i \text{ has an impact on } S_j \\ 0, & \text{if } S_i \text{ does not have an impact on } S_j \end{cases}$$

Stress/stress interactions-A matrix relating direct effects of stresses upon each other (Table 2) was produced by the Technical working group. Primary stresses were listed across rows and down columns of an 18 **x** 18 matrix. The effect of each stress (in the rows) on every other stress (in the columns) was indicated by placing a 1 in the matrix cell if there was a direct and significant effect, and a 0 if there was no direct effect.

The methodology used was predicated on technical knowledge of the participants which allowed them to distinguish between first order and second order stress interactions. For example, it would be possible to perceive a direct and significant effect of PCBs (row 1) on Exotics (column 5) in terms of biomagnification or bioaccumulation. However, as a *stress,* PCBs have no real and significant direct impact on Exotics as an independent stress. Therefore, the cell must be assigned a 0. It is important to allow the matrix to prescribe the significant and direct interactions in the light of the workshop's collective knowledge; in that way the matrix integrates knowledge.

The original matrix completed by the Technical group was revised by comparing their evaluation to identical matrices completed by the other two working groups. Where there was strong agreement in a matrix cell (all three groups voting I), that 1 was transferred to the revised matrix (Table 3). If consensus was not reached among the three groups, the difference was resolved by group discussion and voting. (See Consensus Agreement, Appendix A)

In the original matrix (Table 2) the stresses that influenced the most other stresses were: DAMS, DREDGING, SUSPENDED SOLIDS AND SEDIMENTS (SS & S), and SHIPPING. In the revised matrix, SHIP-

PING was judged to be less important. FISHING was by far the stress affected by the greatest number of other stresses in both matrices, as indicated by ranks of column sums. Similarly, in both matrices, the most interactive stresses were FISHING, SS & S, DREDGING, and DAMS (rank by column sums and row sums).

The model or digraph (Fig. 2) of stress interactions was constructed from the revised matrix because it represented group consensus. The original matrix of stress interactions contained 36% cells with indicator 1's. It was felt that, in many cases, interactions that had infrequent though direct effects were incorrectly included, and that some interactions were assumed or based on inconclusive evidence and should be deleted. The revised matrix, then, containing 16% cells with l's indicating direct interaction, provides a much more meaningful assessment of stress interactions.

The digraph graphically displays a fundamental ecological axiom, namely "everything is connected to everything else." The digraph also suggests certain "activity nodes." For example, SS & S is highly interactive, as illustrated by the number of arrows leaving or entering this cell. Likewise, TOXICS, NUTRIENTS, and FISHING appear as important activity nodes.

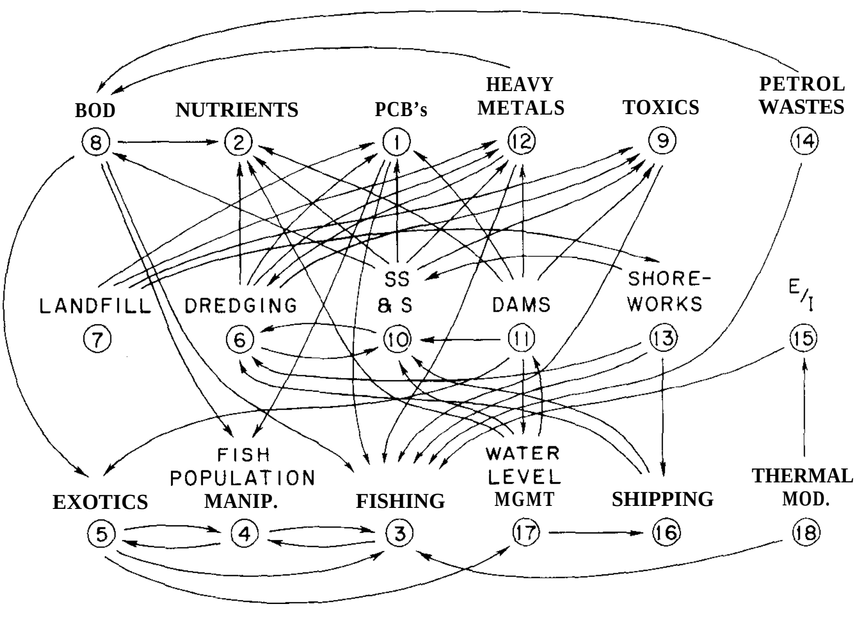


FIG. 2. A digraph of interactions among stresses as constucted from Table 3.

TABLE 2. Matrix relating direct effects of stresses upon each other (effects are displayed row on column).

	PCB	Nutrient loading	Fishing	Manipulation of fish assoc.	Accidental intro. and invasion of fish	Dredging	Landfill operations	BOD loadings	Other toxic and hazardous substances	Suspended solids and sedimentation	Dams and dam removal	Heavy metals	Shoreworks and offshore development	Petroleum wastes	Entrainment/impingement	Shipping disturbances	Water level mgmt.	Thermal modification
PCB			1	1		1	1											
Nutrient loading			1					1			1	1						
Fishing	1	1		1	1								1					
Manipulation of fish assoc.		1	1		1								1		1		1	
Accidental intro. and invasion of fish		1	1	1							1				1		1	
Dredging	1	1					1	1	1	1		1	1	1		1	1	

Landfill operations	1	1				1			1	1		1	1					
BOD loadings		1	1	1	1				1								1	
Other toxic and hazardous substances			1	1		1	1										1	
Suspended solids and sedimentation	1	1	1	1		1		1	1		1	1				1	1	
Dams and dam removal	1	1	1	1	1	1		1	1	1		1	1				1	1
Heavy metals			1	1		1	1	1										
Shoreworks and offshore development		1	1			1				1				1		1	1	
Petroleum wastes			1					1										
Entrainment/impingement			1	1														1
Shipping disturbances	1	1	1			1		1	1	1		1	1	1			1	
Water level mgmt.		1	1							1	1		1			1		1
Thermal modification			1					1							1			

TABLE 3. Revised matrix relating direct effects of stresses upon each other (effects are displayed row on column).

	PCB	Nutrient loading	Fishing	Manipulation of fish assoc.	Accidental intro. and invasion of fish	Dredging	Landfill operations	BOD loadings	Other toxic and hazardous substances	Suspended solids and sedimentation	Dams and dam removal	Heavy metals	Shoreworks and offshore development	Petroleum wastes	Entrainment/impingement	Shipping disturbances	Water level mgmt.	Thermal modification
PCB			1	1														
Nutrient loading																		
Fishing				1														
Manipulation of fish assoc.			1		1													
Accidental intro. and invasion of fish			1	1													1	
Dredging	1	1							1	1		1						

Landfill operations	1								1			1	1					
BOD loadings		1	1	1	1													
Other toxic and hazardous substances			1															
Suspended solids and sedimentation	1	1				1		1	1			1						
Dams and dam removal	1	1			1				1	1		1					1	
Heavy metals			1			1		1										
Shoreworks and offshore development			1			1				1						1		
Petroleum wastes			1					1										
Entrainment/impingement			1															
Shipping disturbances						1				1								
Water level mgmt.		1								1	1					1		
Thermal modification			1												1			

Using this matrix design it is possible to determine strongly connected components of the digraph and the degree to which these components are connected. These strongly connected components can be used to identify clusters of stresses.

The information needed to develop adjacency matrices (Roberts 1976) from which the strongly connected components are deduced is derived from the development of a stress-on-stress matrix showing significant interactions among the stresses.

Stress/user interactions-The Economic working group produced a list of fourteen "User" groups for Green Bay (Table 4).

TABLE 4. "Users" of Green Bay.

1. Sport fishermen	8. Bay and tributary shoreline residents
2. Commercial fishermen	9. Recreational boaters
3. Wet industries	10. Waterfowl hunters
4. Farmers	11. Swimmers
5. Municipal sewage	12. Enjoyers
6. Energy utilities	13. Land developers
7. Commercial shippers	14. Land fillers

Matrices evaluating the effect of each user upon each stress as well as the effect of each stress upon each user were developed. A matrix cell received: a 0 if there was no effect of a row upon a column; a 1 if there was a direct effect of a row on a column: and a 2 for an indirect effect via an institutional process. The number of l's or 2's in columns and rows were counted to determine how the user groups and stresses interact.

As can be seen in Table 5, the stresses directly influenced by the most user groups were FISHING and SS &S; the stresses that influenced the most users were SS & S and WATER LEVEL MANAGEMENT. Users affected by the most stresses were ENJOYERS, SPORT AND COMMERCIAL FISHERS, and WATERFOWL HUNTERS. Although these users are influenced by numerous stresses, they directly influence few stresses themselves. Conversely, WET INDUSTRIES and ENERGY UTILITIES influence more stresses than any other user group, but they are affected by relatively few stresses.

Second order effects, or indirect relationships between user groups and stresses via an institutional process, were judged to be less important except where users such as ENJOYERS, FISHERS, HUNTERS, BOATERS, and SWIMMERS influence stresses. In this case, these groups influence the institutional process through voting, lobbying, and special interest groups.

TABLE 5. User group and stress interactions.

High no. of stresses		High no. of user groups	
User groups influencing stresses	User groups influenced by stresses	Stresses influenced by user groups	Stresses influencing user groups
Wet industries	Enjoyers	Fishing	ss & s
Energy utilities	Sport and corn. fishers	ss & s	Water level mgmt.
Land fillers	Rec. boaters	Nutrients	Nutrients
Mun. sewage	Waterfowl hunters	Toxics	BOD
Land developers	Shoreline residents	Shoreworks	Petroleum

Low no. of stresses		Low no. of user groups	
Swimmers	Farmers	Exotics	Thermal mod.
Enjoyers	Shippers	PCBs	Heavy metals
Waterfowl hunters	Land developers	Dams	Shipping
Shippers	Wet industries	Entrain./Imp.	Entrain./Imp.
Sport and corn. fishers	Land fillers	Shipping	PCBs
	Energy utilities		

Stress/institutional interactions-The list of institutions influencing the Green Bay ecosystem can be considered by area of jurisdiction (local, state, multistate, federal, and international) or by function (direct management, enforcement, planning, research funding, and support activities). The Institutional working group at Green Bay II made a preliminary list of institutions by jurisdiction and then constructed a stress/institution matrix. The function or functions a particular agency performs in relation to each of the stresses was indicated within each matrix cell. From a preliminary analysis of the number of agency-stress interactions for each function a pyramid was diagramed with 38 stress/direct management interactions identified at the top, and 124 stress/support interactions at the base (Fig. 3).

Considerable confusion over agency functions was evident; too many relationships were indirect and the stresses were not organized in ways that institutions deal with them. The task of completing the Institutional matrix was referred to a working group for research and verification of agency functions. This matrix and its interpretation are included in Chapter 4, which considers the institutional aspects of rehabilitation.

Conclusions: Green Bay II - The digraph of stress/stress interactions led us to reexamine the stresses affecting Green Bay. SUSPENDED SOLIDS AND SEDIMENTATION (SS & S), located in the center of the figure, ranked first or second in row, column, and interaction sums of the stress/stress matrix. Thus, although SS & S was relatively low in its

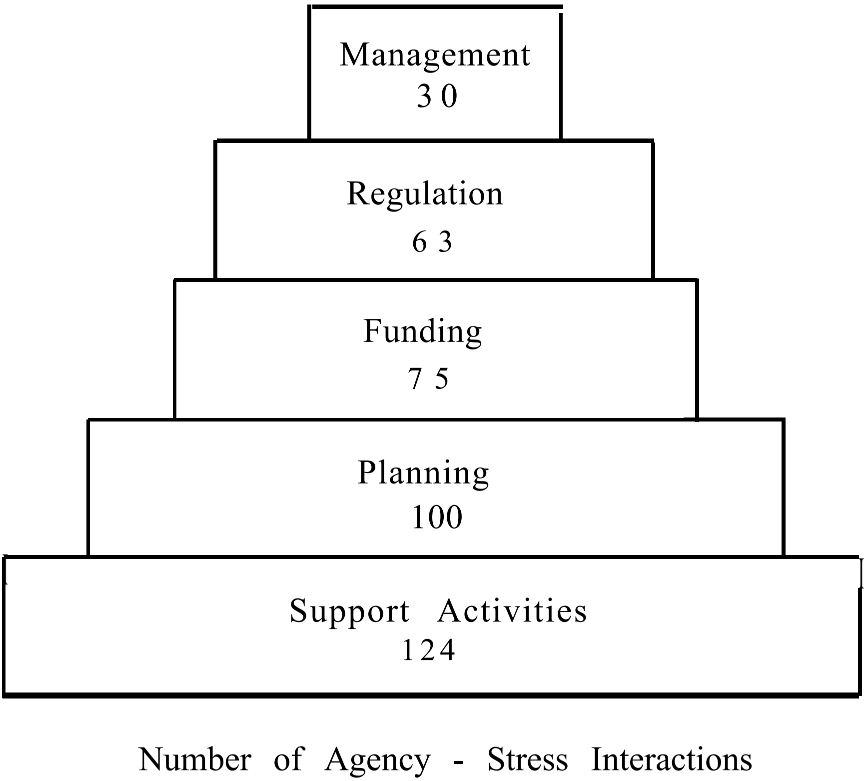


FIG. 3. Number of agency-stress interactions.

perceived importance on the original list of stresses (10th out of 18, Table 1) our analysis demonstrated it to be a key stress in that it affected and was affected by many other stresses. SS & S also influenced and was influenced by a large number of user groups.

NUTRIENTS, on the other hand, was very high in perceived importance (2nd of 18) and was affected by many stresses; but it had no direct effect on other stresses. However, NUTRIENTS as a stress influenced and was influenced by a high number of user groups.

Further evaluation of the stress digraph and stress/user group matrices led us to begin thinking about technical rehabilitation in terms of a group of four notable stresses: TOXICS, NUTRIENTS, SS & S and FISHERIES. Evaluation of SS & S, TOXICS and NUTRIENTS centered around the mechanisms that distribute and redistribute materials in the ecosystem. These mechanisms can be natural physical events (e.g., wind storm runoff) or human activities, including stresses from DREDGING, DAMS, SHOREWORKS, or LANDFILL OPERATIONS. Fishery-related stresses included SPORT AND COMMERCIAL FISHING, the purposeful MANIPULATION OF FISH ASSOCIATIONS (e.g., stocking, size limits), and ACCIDENTAL INTRODUCTIONS OR INVASIONS OF SPECIES (e.g., lamprey, alewife).

During the months between Green Bay II and Green Bay III, two groups of graduate students prepared research papers on the stress clusters outlined above. At Michigan State University-East Lansing, students summarized data and management considerations for NUTRIENTS, TOXICS, and FISHERY stresses affecting Green Bay. Students at the University of Wisconsin-Madison further examined the relationship between human activities (shipping, dredging, toxics, shoreworks, and offshore development) to the stress category, SUSPENDED SOLIDS AND SEDIMENTATION.

Green Bay III

The efforts of research and analyses conducted at Green Bay I and II and at graduate seminars were intended to culminate in a specific product, a proposed management plan. Several activities preceded actual drafting of the plan. First, an additional matrix was developed which evaluated the interaction of stresses and ecosystem components. Next, research documents from the seminars were used to modify the stress list. Working individually and in small groups, important elements of a management plan were identified. Then, group consensus for the preparation of a plan for lower Green Bay was reached: the rehabilitation plan for lower Green Bay would consider TOXICS, NUTRIENTS, FISHERIES, and SUSPENDED SOLIDS AND SEDIMENTS. The plan would also address benefits and costs of rehabilitation and institutional arrangements for implementation.

Matrix development - *So* far the workshops had analyzed how stresses affected each other and users and not how they affected some of the biological and physical components (Table 6) of the ecosystem.

TABLE 6. Biological and physical components of the Green Bay ecosystem.

Biological	Physical
Macrophytes	Water chemistry
Phytoplankton	Sediments
Zooplankton	Currents
Planktivorous fish	Seiches
Carnivorous fish	
Benthos	
Waterfowl	
Humans	

To evaluate these interactions, an additional matrix was constructed during Green Bay III. If the stress had a direct, known effect on one of the twelve components, a I was assigned to the stress/component matrix cell. When the row and column sums for this matrix were ranked, fishery-related stresses and SUSPENDED SOLIDS AND SEDIMENTATION were found to affect the greatest number of biophysical components. Carnivorous fish, waterfowl, sediments, and water chemistry were affected by the most stresses (Table 7).

TABLE 7. Stresses and their influence on the biophysical components of the Green Bay ecosystem.

Stresses influencing the most components:
Fishing
Fishing pop. manip.
Exotics
ss & s
Components influenced by the most stresses:
Carnivorous fish
Waterfowl
Sediments
Water chemistry

Additional insight and information gathered from the matrix analyses and from the graduate research papers led us to a new ranking of priority stresses. Each Green Bay III workshop participant ranked the stresses in two ways: (a) in order of perceived importance to the ecosystem, and (b) in order of perceived importance to bay users. The reranking resulted in a reordering of the top live stresses as follows:

Critical Stresses Influencing the Green Bay Ecosystem

GB I & II	GB III Ecosystem Importance	GB III Human Importance
1. PCBs	1. Nutrients	1. Nutrients
2. Nutrients	2. SS & S / Fishing	2. PCBs
3. Fishing	3. Potential Toxics / Exotics	3. Potential Toxics
4. Fish Pop. Manip.		4. Fishing
5. Exotics		5. Exotics / SS & S

NUTRIENTS now became an important stress in both ecosystem and user rankings. PCBs which were in first place on the original list became second in importance for human users, but placed seventh (along with BOD and manipulation of fish populations) for effect upon ecosystem components. SS & S, which was ranked 10th on the original list of 18 stresses, now tied for second and fifth place ranking in ecosystem and user matrices, respectively. A new category, POTENTIAL TOXICS, was perceived as being very important; in fact, POTENTIAL TOXICS ranked higher than any of the three original microcontaminant categories that were combined to create it, namely, PCBs, heavy metals and other toxics.

Towards a management plan-Participants were divided into working groups to write sections of a rehabilitation strategy that would address the most important stresses. Although some stresses might be perceived as more important than others, achieving a meaningful level of rehabilitation requires that clusters of stresses be managed simultaneously.

The lower Green Bay ecosystem, for purposes of rehabilitative planning, includes ecosystem components, stresses, user groups and institutional aspects. The management plan proposed in the next chapter is, we believe, a balanced ecosystem approach to resource management.

ECOSYSTEM REHABILITATION: A PLAN FOR GREEN BAY

The design of the plan for Green Bay considered several specific requirements. First, it was recognized that rehabilitative efforts should address geographic areas within the ecosystem that manifest the most severe problems. To do otherwise would result in an inefficient application of time and resources. In Green Bay, the lower quadrant of the bay (Fig. 4) was selected as the area of focus, for many reasons: inflow from the Fox River, including industrial and municipal effluents, significantly affects water quality and water mass characteristics of the bay; critical wetlands are concentrated along these shorelines; wind-induced turbulence in these shallow waters keeps sediments in suspension; and the largest concentration of people reside along this area of the bay.

Second, the plan would address problems of erosion and nonpoint source pollution within the watershed. Mitigation of these factors should occur concurrently with other management practices for nutrients, suspended solids and sediments, and toxic substances.

Third, the plan should try to produce the greatest net benefits possible in an equitable manner. The greatest benefits are most likely to be those that affect the most people. For example, if the bay is rehabilitated to support a sustained and diverse fishery, then less sensitive uses such as boating have not been excluded. In that way, both commercial fishers and recreational users (enjoyers, sport fishers, and swimmers) have been accommodated.

This chapter will discuss management strategies for the set of stresses judged to exert collectively the broadest and most significant

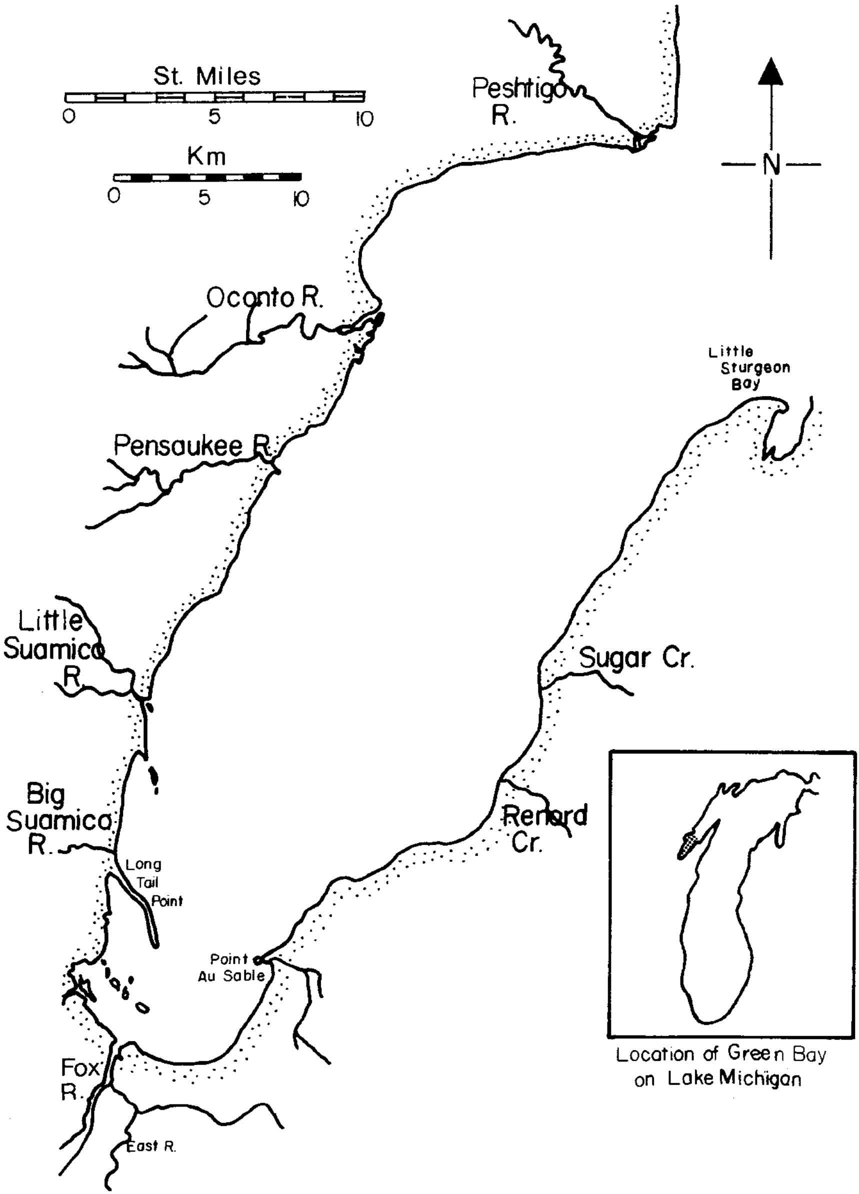


FIG. 4. Map of lower Green Bay and its location in respect to Lake Michigan.

effects upon the ecosystem, the application of hydraulic engineering techniques as a tool for rehabilitating the bay, and the benefits and costs associated with our recommendations for management.

Nutrient Management

A continual influx of nutrients, particularly phosphorus and nitrogen from point and/or nonpoint sources, contributes to the highly eutrophic state of lower Green Bay waters. In addition, phosphorus is reintroduced to the water column by wave action stirring bottom sediments and mixing nutrient-rich interstitial water with overlying water (Sager et al. 1977). The frequent occurrence of resuspension and the fact that municipal effluent discharges mostly attain phosphorus levels of 1.0 mg/L mean that immediate, sizable reductions in phosphorus loading are unlikely. Nevertheless, programs to reduce external and internal nutrient cycling must be implemented and/or accelerated if changes in the trophic status of the bay are to be realized.

Many of the data required to bring about these changes are unavailable or need to be refined in a usable format. For effective planning the following information is necessary:

- an updated nutrient budget for the lower Fox River drainage basin;
- an estimate of the relative importance of internal nutrient recycling;
- a realistic nutrient model for the lower bay, and an estimate of how much of the primary productivity is going to other trophic levels.

Studies funded by the Fox Valley Water Quality Planning Agency, the Wisconsin Department of Natural Resources (WI DNR), and the UW-Sea Grant Institute have applicability and should be put into a useful format for rehabilitation planners.

Nutrient control should be managed by two general approaches: reduce loadings from external sources (both point and nonpoint) and reduce the internal recycling of nutrients. Ideally, a model for nutrient management would consider both external and internal nutrient sources. A refined model for Green Bay does not exist at the present time, but sufficient information is available to construct crude models which can suggest courses of action appropriate to rehabilitation strategies.

Dillon and Rigler (1974) developed a temporal model which has potential applicability for Green Bay. They observed changes in the eutrophic status of Lake Washington which indicated that a linear reduction in chlorophyll *a* followed reduced levels of total phosphorus. To date, there is insufficient information to construct a temporal chlorophyll/

phosphorus model for Green Bay. However, data from Sager et al. (1977) permit the construction of a spatially determined regression model of chlorophyll *a* on phosphorus concentrations during the summer months (Fig. 5). This regression is similar to chlorophyll/phosphorus relationships observed by Sloey and Spangler (1977) for Lake Winnebago, the headwaters of the lower Fox River.

Recognizing the limitations of the spatial model, we can cautiously suggest that a reduction in total phosphorus concentrations of 75%, from 0.20 to 0.05 mg/L, will be required before chlorophyll levels fall to a point where water clarity and aesthetic quality are significantly improved. A correlation between total phosphorus loading from the Fox River and total phosphorus concentrations in lower Green Bay is known to exist (Sager et al. 1977). However, only 50% of the variability in summer phosphorus concentrations can be accounted for by river loadings. These observed relationships demonstrate the importance of internal loading of phosphorus in Green Bay; but exactly how much is due to internal sources and how much is due to external sources remains questionable. It seems clear, however, that both aspects must be addressed in a rehabilitation plan.

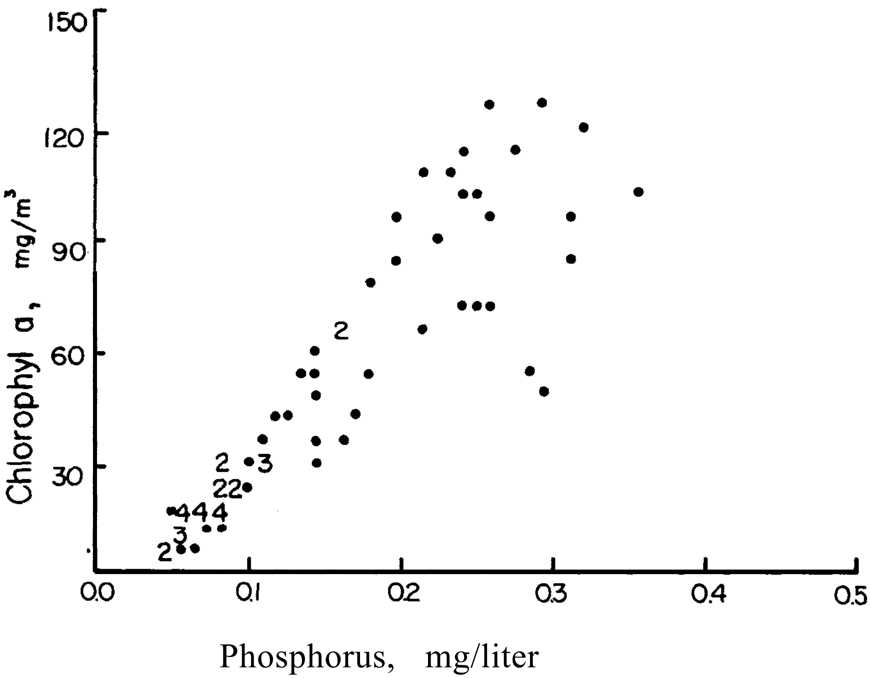


FIG. 5. Relation between chlorophyll a and phosphorus content of water among locations in Green Bay (data from Sager et al. 1977).

External nutrient control measures-Nutrients entering lower Green Bay from external sources originate from both point and nonpoint sources. Much has been done over the past decade to reduce phosphorus loadings from point sources. Most dischargers are approaching compliance with the prescribed 1.0 mg/L total phosphorus effluent standard (Great Lakes Basin Commission 1979). High costs, but only minor benefits, are anticipated from improved phosphorus removal at already existing treatment plants. Nevertheless, when new treatment facilities are constructed it may be possible to design for phosphorus reductions significantly below the 1.0 mg/L level, with relatively little additional cost (Great Lakes Basin Commission 1979). Such efforts should be encouraged, but for the present, increased technological control will offer only limited reductions in total phosphorus loading.

Nonpoint nutrient control measures offer the greatest potential for reducing nutrient loadings to the Fox River. Land management practices, including improved soil and water conservation can effectively reduce nutrient loading while benefiting farmers. Some agricultural methods which keep plant and animal nutrients out of watercourses may, in turn, increase nutrients and water available to crops.

For example, farmers can sod waterways, practice contour farming, and construct animal waste-holding facilities. Liquid manure pits, which allow farmers to avoid spreading animal manure over frozen ground, reduce the amounts of waste nutrients lost from the land during spring runoff. Minimum tillage of fields also reduces surface runoff and nutrient losses from agricultural lands. These techniques, which have been shown to result in a reduction in farming costs (Sharp and Bromley 1978) should be initiated as demonstration projects in the Fox River drainage basin. Realization of economic and resource benefits could entice the farming community to adopt practices which are more favorable to control of external nonpoint nutrient loading.

Urban runoff, which constitutes -24% of the yearly phosphorus load to Green Bay (Sager and Wiersma 1975), is another diffuse source of nutrients. These sources are difficult to control, but some minor reductions might be achieved by using temporary catch basins, directing storm water through grassed waterways or wetlands, and more efficiently collecting leaf litter from the streets. Conventional wastewater treatment of urban runoff is not likely to be used, but could be considered as an alternative in particular urban regions, such as industrial parks, which may have high nutrient content in their runoff.

Internal cycling control measures--Internal recycling of nutrients from sediments is an important source of phosphorus, especially for shallow water bodies such as lower Green Bay (Holdren 1974). Internal nutrient cycling rates are influenced by physical factors such as wind-induced sediment resuspension, currents, and seiche action, and by chemical factors such as anaerobic conditions which cause rapid release of phosphorus from sediments. Biological cycling of nutrients involves uptake and retention by algae and macrophytes, degradation and excretion by detritus feeders and herbivores, and final loss to the sediment sink. Manipulation of nutrient cycle compartments or cycling rates would be one way of controlling internal cycling.

Carp, for example, are known to promote resuspension of shallow water sediments and to excrete high levels of phosphorus; manipulation of the carp population might therefore enhance water quality. Barrier islands constructed in the lower bay would reduce wind-induced resuspension and wave action. These islands could be constructed from navigational dredge spoils or by relocating materials, i.e. old dredge spoils, from shallow areas (see Hydraulic Engineering section, p. 46).

SEDIMENTS AND SUSPENDED SOLIDS

Water turbidity in lower Green Bay detracts from at least half of the identified uses (Table 4). Turbidity depends upon the amount of suspended solids in the water column, arising from influxes of silt and clay from the watershed, resuspended bottom sediments, and algae. Because phosphorus cycling from sediments stimulates algal growth and the resuspended sediments also contribute to turbidity, management practices which prevent sediments from reentering the water column will improve water clarity. Some techniques, such as alum precipitation which have been used in other inland lake renewal projects (Dunst and Born 1974) are not feasible for a body of water as large as Green Bay.

Practices which may prove applicable for Green Bay are (1) in-lake structures to reduce the effects of wind generated waves and currents and (2) rough fish removal or control. Barrier islands, described on pages 34-36, can reduce wind-induced resuspension of sediments by altering wave height, period and orbital velocity (Chesters and Delfino 1978). The *overall* extent of sediment resuspension would be reduced by the islands, but sediment delivery from the Fox River will continue and if the island shelter effect exceeds the critical balance, the sediment-protection project could become a landfill project. Careful planning will be needed in this regard.

Rough fish control in Green Bay presents a particularly challenging problem. The relationship between carp, resuspension of sediments, and nutrient cycling has been documented (Shapiro 1974). However, an estimate of the impact of carp on rooted aquatic plants and disturbance of bottom sediments in Green Bay has not been determined. These relationships need to be understood before the effectiveness of carp control can be assessed for Green Bay.

REHABILITATION OF THE FISHERY

Although species composition has shifted dramatically under the influence of human activities, fish production based on commercial catch statistics in Green Bay is still greater than any other area of Lake Michigan and most other areas of the Great Lakes (Great Lakes Commercial Fishery Statistics). Rehabilitation efforts will seek to enhance the fishery by altering the present composition of the fish community to a more desirable mix of species through a combination of stress removal and the direct manipulation of the fish populations and their habitats. In some cases, this will require the use of conventional single-species management tools such as size limits, harvest quotas, and stocking programs. In other cases, considerable method and design development is needed. In all instances, the selection of priorities for rehabilitation should involve the interaction of the stresses and, whenever possible, given the "state of the art," should consider the entire fish community.

Carp control-The abundance of carp affects the general state of the ecosystem and critically constrains effective management of the lower bay. This species, because of its large population and spawning and feeding behaviors, increases internal nutrient cycling, turbidity, and resuspension of sediments; disrupts macrophyte communities; and interferes with successful reproduction of other fish species. The need for control is evident; the method certainly is not. Advances in the area of pest control have been great in recent years. The practices being developed through the ideas of integrated pest management in agriculture plus successes with lamprey control in the Great Lakes suggest to us that carp control in Green Bay is an approachable problem. The tendency for carp to aggregate in winter near inlets (Johnson and Hasler 1977) and in response to temperature in summer provide a clue to potential methods of capture using as yet undeveloped techniques.

A program to study the impact of carp on this ecosystem and the potential methods of reducing carp abundance should be initiated. Because high PCB levels in Green Bay carp could create disposal problems if large populations of carp are harvested, alternatives for final disposal and potential for marketability should also be considered. As the PCB stress is lessened, disposal and marketability problems should ease.

The yellow perch fishery--Annual harvest of yellow perch *(Perca* flavescens) now averages one-fourth to one-half less than the 1 million lb harvested prior to the mid-1960s (Griffin 1979; Bishop et al. 1978). The current fish stock is managed by commercial size limit only, and the fishery appears to be suffering from excessive cropping of fish well before they realize full reproductive potential. Appropriate harvest quotas, limited entry, zoning, and size limits for the commercial and growing sport fishery should be established as a first priority. Along with the rehabilitation of a stock of spawning age perch, the reestablishment of spawning and nursery areas and the design of artifical spawning and nursery areas should be considered. The development of rearing ponds might provide an alternative to direct habitat rehabilitation until carp removal programs become effective.

Stock rehabilitations-*Improvement* of water quality in the lower bay will allow numerous species, such as walleye *(Stizostedion vitreum vitreum),* white bass *(Morone chrysops),* largemouth bass *(Micropterus* salmoides), northern pike *(Esox lucius),* and black crappies *(Pomoxis nigromaculatus),* to be reestablished to provide fishable populations in the lower bay. In some cases, stocking will be required to take immediate advantage of improved conditions. For example, efforts by the Wisconsin DNR to reestablish a walleye fishery by stocking are meeting with success and should be continued. The walleye represents a rehabilitation option with high potential for the lower Fox River, lower bay, and mid-bay areas in particular. Marketing problems associated with flavor quality of the walleye are, however, recognized.

Managing the forage base-Ideally, a multispecies management plan will include judgments based on the interactions of commercial and game species with their forage species. Species such as the spottail shiner *(Notropis hudsonius)* and trout-perch *(Percopsis omiscomaycus)* are abundant in the lower bay. Little quantitative data are available on the ecological role of these species, but they are assumed to be important for the success of the developing walleye populations as well as for future populations of other predators. If abundant, they should also help reduce predator pressure on yellow perch.

Underutilized species-Some species that are abundant in Green Bay could be used more widely in both commercial and sport fisheries. Two fishes in particular, the burbot *(Lota lota)* and white sucker *(Catostomus commersoni),* have economic potential; research on population traits, distribution, and marketability should be encouraged.

Other traditionally important species are not utilized owing to contaminant and palatability problems. For some time, the eating quality of perch and walleye taken in the sport fishery area below the DePere Dam and extreme lower bay has been viewed as poor. Research to identify the origin of contributing factors seems appropriate. In addition, preparation methods might be developed which could enhance the eating quality of these fish, leading to greater utilization of the fishery. Of course, the elimination of the PCB problem is central to encouraging the harvest of several species, particularly carp and alewife.

Spawning ground and river habitat rehabilitation-*Most* of the major tributaries to the lower bay have been chemically and biologically altered. These riverine environments should be regarded as critical areas for rehabilitation. Management strategies should consider natural and artificial habitat enhancement and the removal or modification of migration barriers, such as dams, to allow fish to move upstream to spawn and establish upstream populations. River as well as lake strains of some species might also benefit. For example, river strains of lake herring

(Coregonus artedii) might be reestablished. On the other hand, dams may act as an effective barrier to encroachment of undesirable species. If, for example, migration of the lamprey attempts to extend into the Fox River, locks and dams already situated on the river would be an effective preventative barrier.

TOXIC SUBSTANCES

Effluents discharged into the lower Fox River by industries and municipalities present a complex set of problems for rehabilitation managers. PCBs, along with many other potentially hazardous chlorinated organic compounds and resin acids, require immediate attention. For the present, heavy metals, pesticides and petroleum wastes are not perceived as significant problems in Green Bay.

PCBs (polychlorinated biphenyls)-PCB concentrations in Green Bay fish are not declining as rapidly as levels recorded for Lake Michigan as a whole. These compounds, which become associated with suspended solids during industrial processing or wastewater treatment, enter the Fox River system and bioaccumulate in fish; PCBs are potentially toxic to humans (U.S. EPA 1978). Along the Fox River some paper recycling mills still inadvertently discharge up to 1 lb/d of these compounds, but at least one mill has developed the technology for improved removal of suspended solids from their effluent (T. Sheffy, personal communication). While improved waste treatment could substantially lower PCB levels in Green Bay, there is no current legal requirement for paper mills to treat wastes this effectively.

Chlororganic compounds-Research programs that will identify, quantify, and characterize the various chlororganic compounds in paper mill and sewage treatment plant effluents must be actively supported. Little information is available on many of the chlorinated organic compounds that arise from waste treatment. Ideally, once toxic compounds have been identified, they should be regulated by EPA (Environmental Protection Agency) standards. These standards can be included in Wisconsin Pollution Discharge Effluent permits.

Monitoring toxics - Before toxics in the ecosystem can be managed, they must be identified and monitored in water samples, sediments, and biota. Toxic substances associated with sediments could be managed in three ways: remove contaminated sediments and enclose in safe areas, bury with clean sediments, or protect from resuspension. It might be possible to remove PCBs concentrated in carp, for example, by harvesting carp populations. The costs and benefits of carp removal might compare favorably with sediment control measures. Whatever management strategies are considered, the public should be fully informed of the hazards associated with toxic substances in Green Bay.

Although paper mills are required to self-monitor effluents discharged into the Fox River, the DNR does conduct occasional compliance monitoring to confirm the discharger's results. Effluent components reported include only conventional pollutants and a few suspected toxic substances. For rehabilitation and effective ecosystem management, regulations should require industries to monitor a wider range of compounds (Sullivan and Delfino 1982).

A few species of fish in the bay are monitored for PCB concentrations by the WI DNR. Yellow perch, which comprise 90% of the commercial harvest from lower Green Bay, should be more extensively monitored, and bullheads, walleyes, suckers, northern pike, carp, and spottail shiner should be surveyed as well. The high costs of such a monitoring program have seriously limited numbers of fish that can be tested. However, some fish species are presently monitored by the WI DNR for a few other chlororganic compounds known to be present in paper mill effluents. The program, however, needs to be expanded to determine if there is evidence of bioaccumulation of these compounds in carp and yellow perch populations in the Fox River and lower bay.

Hydraulic Engineering

Some aspects of rehabilitation, such as the creation or reestablishment of wetlands and the development of harbors of refuge may best be achieved through hydraulic engineering. Manipulative design, however, carries the potential for adverse effects as well as benefits. Design for hydraulic engineering structures should therefore maximize benefits and minimize adverse potential for the specific set of conditions to be altered.

Shoreworks-Shoreworks are engineering structures designed to protect the land from destructive lake forces or facilitate access to the lake. A comparison of the benefits and potentially adverse effects of various shoreworks is listed in Table 8.

Dredge spoil islands and dikes-Construction of dredge spoil islands and dikes offers the most promising ratio of beneficial uses to adverse effects for rehabilitation of the lower bay through hydraulic engineering. Figure 6 illustrates possible construction design which would incorporate all of the beneficial aspects listed above, while minimizing adverse effects upon the ecosystem. These islands could create many acres of new habitat (Fig. 7).

In designing islands for dredge disposal, several features should be considered:

a) dredged material must be adequately confined to prevent leaching of pollutants and washout of fine particles;
b) island boundaries should be stabilized against wave attack with riprapping;

TABLE 8. Benefits and potential adverse effects associated with shoreworks construction.

Benefits	Adverse effects
Riprapped shorelines	
- Reduced sedimentation and suspended sediments from shoreline erosion - Shelter for fish communities	- Barrier to exchange of nutrients and water between bay and wetlands - Land disturbance during construction
Groins	
- Reduced sedimentation and suspended sediments from shoreline erosion - Shelter for fish communities	- Barrier to natural flow of littoral sediment transport - Can accelerate erosion - May occupy spawning habitat - Land disturbance during construction
Jetties and **docks**	
- Access for fishers, enjoyers, boaters - Habitat for gulls - Shelter for fish communities	- Barrier to natural flow of littoral sediment transport - Can accelerate erosion - May occupy spawning habitat - Land disturbance during construction
Dredge spoil islands and dikes	
- Establish recreational areas intimately linked to the bay - Shelter for boats - Reduce resuspension of sediments **by** reducing effective wind stress and resulting wave action - Nesting areas for gulls, terns, cormorants - Suitable areas for construction of carp traps	- Alter bay circulation - Occupy fish spawning or nursery areas - Land and bay disturbance during construction - Change in sediment type **toward silt** and clay, less sandy areas **due to** increased settling of finer sediments - Potential conflict with shipping operations

c) planting vegetation can reduce wind erosion of island surface features;
d) a shelter belt of trees can reduce wind stress over adjacent waters of the bay;
e) trees or tall frames and platforms can provide cormorant nesting habitats, and gravel rock beaches can provide areas for gull and tern nesting;
f) the absence of a land bridge to constructed islands will prevent access by terrestrial predators;
g) fish spawning areas can be provided by shallow water gravel and boulder beds adjacent to islands; and
h) small-gated lagoons can be used for carp entrapment.

FIG. 6. Example of diked island-possible surface structure design.

An obvious concern in the construction of new islands is their impact on circulation and sedimentation patterns. The present condition represents a balance between silt deposition and sediment resuspension and transport. Artificial islands will likely shift the present balance. To determine where the balance should be struck will probably require extensive modeling (physical and numerical) and a much better historical knowledge of wave and seiche activity.

Riprapping - In contrast to the potential effectiveness of dredge spoil islands and dikes, riprapping is a very costly and unaesthetic effort which

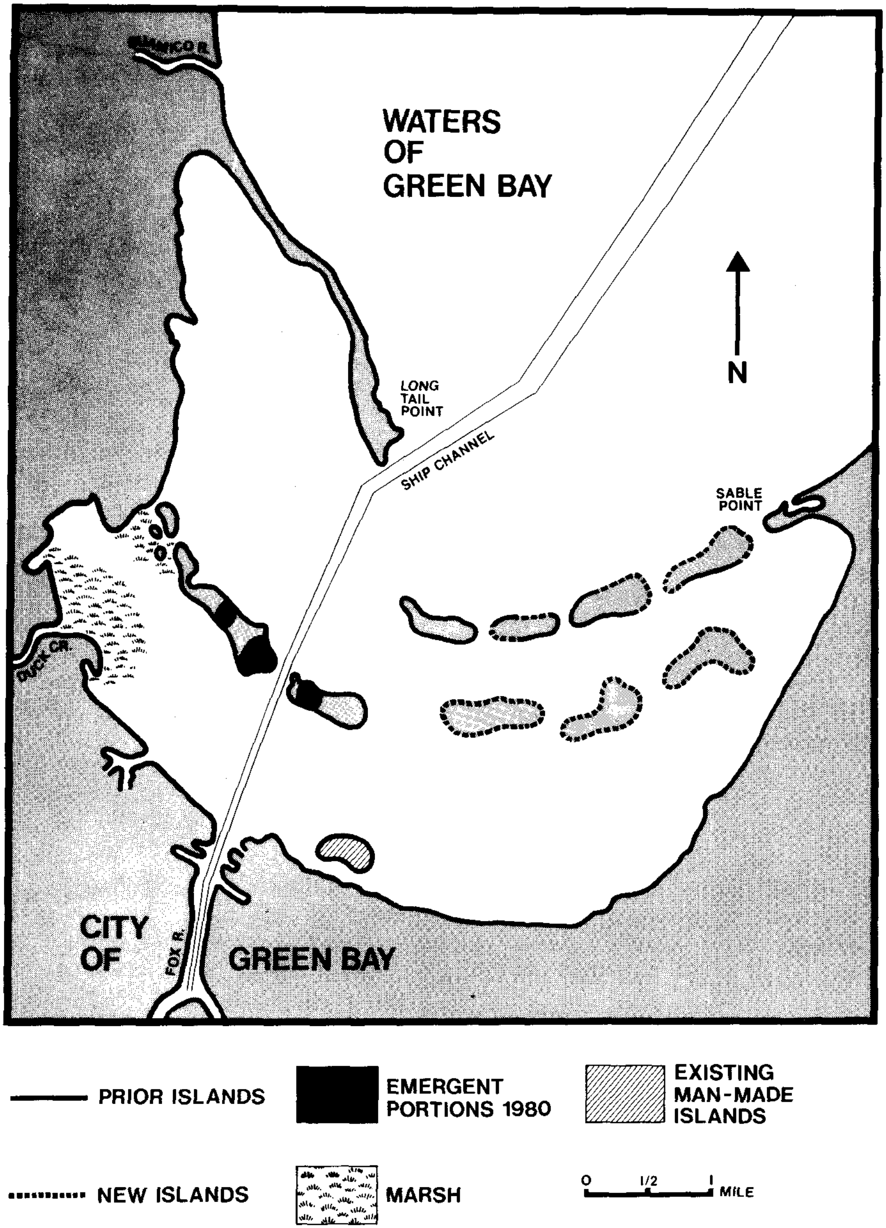


FIG. 7. Example of diked islands-possible locations.

can be only partially and temporarily effective for rehabilitative purposes. The process is generally not recommended, except where critical high-value facilities, such as power plants, industries, roads, or water treatment plants need to be protected.

The most beneficial effect of riprapping is the reduction of sediment loading from shoreline erosion. The most serious adverse effect may be the prevention of nutrient and water exchange and passage of some fish species between bay and wetlands. To reduce the adverse effects and increase the beneficial aspects, the following recommendations can be made:

Wetland shorelines: Discourage additional riprapping; the shoreline is low and erosional loadings are relatively low.

Bank and bluff shorelines: Riprapping is generally not effective in reducing bank/bluff erosion unless combined with other measures. Property owners may also need to regrade bluffs to stable slope angles, revegetate slopes, dewater bluffs or banks, and divert surface water drainage from bluff faces and edges (Sterrett 1980). Riprapping can, however, be effective in preventing toe erosion, i.e. erosion at the foot of bluffs due to destructive wave action and other lake processes.

Jetties and groins-These structures also inhibit the natural movement of sediment within the bay and have not been included as a specific design for rehabilitation of the lower bay.

Engineering response to entrainment/impingement-The problem of entrainment and impingement of yellow perch is a serious, albeit localized, stress that can be mitigated by engineering design. The water intake system of the Pulliam Power Plant, located at the mouth of the Fox River, entrains many young perch. One solution to the problem would be to modify or replace the existing structure. A rock and timber intake crib, as sketched in Fig. 8 could keep young fish out of the intake pipe and prevent impingement. A cost analysis study may indicate the feasibility of a state/industry cost-sharing approach to alleviate this stress upon the yellow perch fishery.

DREDGING

Shallow and shoaling areas of the bay and Fox River have been dredged to maintain adequate navigation depths in the commercial shipping channels. Several recreational home developers have also dredged areas of the east and west shores to create inland channels where home owners can moor boats. In addition, dredging is being considered for proposed recreational harbors at Oconto and Long Tail Point.

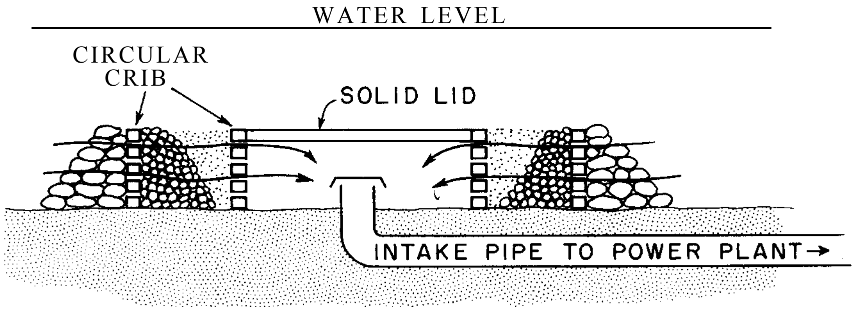


FIG. 8. Design of a water intake crib which would avoid problems of fish entrainment and impingement.

Dredging should be critically evaluated for both beneficial and potentially adverse impacts upon the ecosystem. Some of the factors, to be considered, are listed in Table 9 below:

TABLE 9. Dredging considerations.

Benefits	Adverse Effects
Continued access for commercial vessels to major bay ports (of significant economic importance)	- Disruption or destruction of benthic communities
Additional boat moorage and docking areas for recreational boaters	- Creation of temporary turbidity and adverse water quality conditions, i.e. increased BOD, COD, release of toxic chemicals
Removal of sediment deposits, particularly toxic chemical "hotspots"	- Disposal problems associated with sizable quantities of soil, much of what may be polluted; possible contamination of soil and groundwater
Improved habitat diversity within marshes by selective chaneling and filling	- Alteration of upland or wetland areas where channels are created
Removal of fine-grained sediments from the sedimentation/resuspension cycle in the shallow lower bay	

Utilization of dredge spoils-At the present time Wisconsin classifies *all* dredged material as polluted. In-lake disposal of dredged materials, except in approved containment facilities such as the newly constructed island in Green Bay, is strictly prohibited. Material of this nature classified by EPA as polluted is also subject to Wisconsin solid waste management regulations. In contrast the State of Michigan takes a case-by-case approach to dredging and dredge spoil disposal that offers a more flexible permit review process.

A similar approach in Wisconsin could have the effect of efficiently utilizing dredge spoil materials. For example, clean spoils could be used for beach nourishment and refurbishment of eroded shore zones. In addition, clean dredged sediments could provide a means of burial for existing contaminated "hotspots." Under current Wisconsin policy, these beneficial uses cannot even be considered. It is recommended that dredging permit review policies be reexamined in the light of potential beneficial uses for clean spoils and technological advances in the disposal of contaminated spoils.

Reestablishment of wetlands-Considerable experimentation with the reestablishment of salt marshes has been conducted, particularly along the east coast of the U.S., but experience with freshwater coastal marshes has been limited (U.S. Dredge Material Research Program). The potential for beneficial improvement is substantial, however. It is estimated that 60% of the original wetlands of the west shore of Green Bay has been lost (Bosley 1978); the use of dredge spoils associated with channelization offers the potential means for creating new (albeit artificial) wetlands.

DAMS AND DAM REMOVAL

Dam removal can be an effective rehabilitative strategy and is already under consideration in the case of one tributary which enters the bay.

In 1980 Wisconsin Department of Natural Resources (WI DNR) successfully prosecuted Scott Paper Company of Oconto Falls for WPDES permit violations. The state received $1 million for environmental damages, and the WI DNR is utilizing this money for fishery rehabilitation of the Machickanee flowage, an upstream portion of the Oconto River. The river has several dams which prevent fish movement between the river and bay. Because of strong local influence, rehabilitation efforts are being aimed at the landlocked walleye population. One rehabilitation alternative would be to remove one or more of the dams. This step would increase the limited riverine habitat that is so valuable to stream spawning fish. Granted, dam removal could be expensive and pose unknown environmental risks, but this represents the type of innovative management that could be initiated.

ADAPTIVE MANAGEMENT STRATEGIES

The lower bay ecosystem must be regarded as an ever-changing system. Phosphorus and BOD loadings, hazardous substance spills, and other changes in water quality allow or precipitate changes in the fish community. The U.S. Fish and Wildlife Service, for example, presently monitors the lower Fox River for anticipated changes in movements of sea lamprey populations. Management strategies created as a result of present conditions may become inappropriate at some point in the future. As rehabilitation proceeds, strategies must be revised in light of changes in water quality and the biotic community that may have occurred.

Adaptive assessment and management workshops developed by Holling (1978) and applied to several Great Lakes fishery problems (Koonce et al. 1982) provide the type of framework required to adapt the management plan for Green Bay to meet changing conditions.

AN OVERVIEW OF COSTS AND BENEFITS

Although users and managers alike would agree that the value of a "clean" Green Bay is high, that fact alone does not help planners and managers estimate the total values and costs of proposed activities to rehabilitate the bay to clean water standards. It is important to recognize that management decisions are most appropriately based upon the "marginal costs" and "marginal benefits" of activities, rather than total values (Francis et al. 1979). Marginal costs and benefits are the additional costs and benefits attributable to an incremental change in the relevant activity. For example, there is some evidence that achieving further reduction of phosphorus levels from point sources entering the southern part of Green Bay (i.e. a "marginal" change) would cost more than the additional benefits received, because the total phosphorus load including nonpoint sources is now so great that such reductions would be meaningless. In other words, the marginal costs would be greater than the marginal benefits, even though the total costs of point source control appear to be less than the total benefits.

Assessing marginal costs and benefits-The rehabilitation plan framed by the workshops represents the collective judgments of people with widely divergent backgrounds and as such, implicitly reflects the values of an enlightened public. Thus, subjective judgments of marginal costs and benefits were made explicit in the rankings of critical stresses. These evaluations may be the most precise estimates of benefits and costs of rehabilitative measures for Green Bay now available. Because almost no estimates of specific dollar values of either benefits or costs of proposed rehabilitation strategies were available, none of the usual quantitative comparisons of benefits and costs were attempted. Rather, this section discusses marginal costs and benefits that might accrue from specific recommendations for rehabilitation. Many of these values are difficult and costly to estimate, even though they would be of great help in a planning exercise such as this. However, the subjective judgments of a diverse group such as this should not be taken lightly. They probably are not far off.

Plans for rehabilitation of the lower bay center around four technical strategies: nutrient management, toxics management, hydraulic engineering, and fishery management. We have attempted to outline only the most significant benefits and costs relating to each strategy. Because all four strategies aim at rehabilitating the bay, most benefits and many costs arising from implementation relate directly to user groups. Where this association seems obvious we have not bothered to repeat it in the outline beyond an initial entry, but have simply presented any additional or unique considerations.

To evaluate marginal benefit/cost parameters, user groups that influence and will be influenced by rehabilitative changes were divided into two major groups. One group of users can be characterized as using the bay for a sink, and includes users such as farmers, whose activities allow phosphorus and/or soil particles to reach the bay, users who contribute treated or untreated waste water to the bay, and those who allow disturbed soil to wash to the bay. Other user groups "gather the fruits" of the bay, and include sport and commercial fishermen, as well as "enjoyers" who derive satisfaction simply knowing that the bay is not degraded and will be available for future use and enjoyment. Enjoyers also place a high value on maintaining the bay as an intrinsically special environment and habitat.

Identifying user groups-Each of the user groups identified at the Green Bay II workshop was analyzed by graduate students in a seminar at Michigan State University-East Lansing according to numbers of users and their economic importance to the region. As data on user group size and economic importance was not uniformly available or reliable for all user groups, the resulting weighted values contained a definite element of educated guesswork. In addition, the investigators did not produce a strictly ordinal list, but limited the weighted values to three categories of user significance as follows:

Major user significance	Intermediate user significance	Minor user significance
Sport fishers	Energy utilities	Commercial shippers
Commercial fishers	Recreational boaters	Waterfowl hunters
Wet industries	Bay shoreline residents	Land developers
Farmers	Tributary shoreline residents	Land tillers
Municipal sewage		
Enjoyers		
Swimmers		

Nutrient Management

Nutrient overloading of lower Green Bay is highly visible as algal blooms which impact a variety of the bay's user groups. The presence of suspended solids and sediments is a related stress which confounds the situation and further limits many people's use of the bay. Both stresses arise from two primary sources, farms and urban areas, which can be treated separately for management purposes. Generally, nutrient control focuses on limiting phosphorus and suspended solids inputs into the ecosystem.

FARMERS rely upon the ecosystem's assimilative capacity and contribute significant nutrient inputs into the bay watershed. A variety of agricultural practices not widely used by most farmers could, if used on a broader scale, substantially decrease the phosphorus loading in the system. Some of the costs to farmers would include: (a) the initial cost of capital outlay for conversion to new methods; (b) information costs, or the value of the time it takes to learn about the new practices; (c) learning costs (while learning and experimenting with new methods, some farmers may make potentially costly mistakes); and (d) lower profits from some phosphorous-reducing practices. In the long run, however, many farmers would apparently increase profits from practices such as "conservation till" methods and better fertilizer recycling.

The major benefit to the public will, of course, be substantially improved water quality. Costs to the public associated with farming changes may result from (a) subsidies paid to farmers for conversion; (b) transaction costs for administrative activities; (c) information dissemination to farming communities; and (d) research costs toward further technological development. Other impacts might result from shifts in demand for chemical fertilizers. These shifts could create both benefits and costs to manufacturers. Similarly, research and technological design changes in farm machinery may result in new costs and benefits to those manufacturers.

MUNICIPALITIES comprise the other major user group that contributes substantially to nutrient loading of the bay. Point source pollutants are derived from municipal sewage treatment plants, and nonpoint source pollutants include runoff from urban storm drains. Limiting inputs from municipalities could result in costs and benefits which parallel those outlined above for farmers.

For instance, reducing nutrient loadings from sewage treatment facilities would probably call for an increase in the number and/or capacity of such facilities, and changes in their technology. Such measures would ultimately be paid for by the taxpayers. In contrast, many enjoyers of a less eutrophic bay live elsewhere and pay few taxes to any geographic unit that controls nutrient inputs into the bay.

If storm drain runoff is shown to be an important source of nutrient loading, it could seriously influence residential use of lawn and garden fertilizers. In turn, industries that supply the implicated products would be affected.

WET INDUSTRIES. i.e. the Fox Valley's pulp and paper mills, are currently required to treat their effluent, primarily for BOD and nutrient loading. Costs of this nature accrue directly to the industry. It should be noted, however, that wherever production costs go up, the increase is passed on to consumers via higher prices and/or the industry suffers from lower profits because of higher costs and/or lower sales. It is conceivable that these industries may at some time even require support from the public in the form of no-interest loans or other subsidies to make the technologic changeovers necessary to comply with effluent standards.

LAND FILLERS, LAND DEVELOPERS, AND COMMERCIAL SHIPPERS will accrue costs, though relatively slight in comparison to other user groups, as they are required to control further their practices to achieve reduced nutrient and suspended solid loading.

Additional costs of nutrient management-General costs will be incurred as scientists and managers undertake additional studies aimed at refining nutrient management strategies, such as:

1) a demonstration project on nonpoint source nutrient control, carried out on a representative segment of the watershed;
2) further information development on the ecosystem's nutrient budgets (particularly for the Fox River drainage system), internal recycling rates, and the relationship between fish production and nutrient levels;
3) a much-needed carp control program for lower Green Bay, which will require expenditures for further research as well as implementation.

Benefits that accrue to user groups-User groups affected by, but not directly responsible for, nutrient and suspended solids and sediments loading will realize the greatest benefits from nutrient management. Enjoyers, for example, will realize enhanced aesthetic attributes of the bay and have the assurance that the ecosystem is healthier and will be available for future use and enjoyment. Recreational boaters and swimmers will benefit by improved access to the bay and generally more pleasant conditions for their activities. Bay shoreline area residents will enjoy similar benefits and may in addition gain from increased property values. Sport and commercial fishermen may benefit from greater species diversity and will also profit from reduced numbers of less desirable species.

TOXICS MANAGEMENT

The subject of toxics seems inextricably intertwined with some emotional concerns and, as a result, there is a serious problem of real versus perceived dangers. This calls for programs of immediate and on-going public education. The public will be largely responsible for the costs of such efforts, but will also reap the rewards. Some industries may share these costs, but to a lesser degree.

The task of testing compounds to evaluate their toxicity is herculean. Funded primarily by public monies, such research is expensive, averaging approximately $3 to $5 million *per compound.* Unfortunately, EPA has scarcely made a dent in investigating the present list of suspected toxicants. The decreased risk to society from exposure to harmful substances counterbalances the enormous research costs, however.

Toxics in Green Bay constitute a problem largely confined to the southern end of the bay, except for a few isolated areas. By far the greatest source of toxic materials is the watershed's pulp and paper producers. At present a Wisconsin Sea Grant-supported study to inventory potentially toxic compounds associated with pulp mill wastes is underway. Related studies modeling the fate of these compounds is likely to be the most troublesome aspect of the study and will not be completed until 1984, at the earliest. Even armed with this data, the task of establishing toxicity levels for organisms in the bay, as well as for humans, remains to be done.

Potential costs-Once toxicity levels are recognized and regulated, toxics management will most likely take the form of pretreatment of wastes on-site at industrial plants.

Pulp and paper industry-In many cases, solid precipitates may result from pretreatment and require landfill disposal. Costs that accrue to landfill disposal involve location assessment and development, as well as monitoring of containment sites. If the landfills leak, groundwater contamination may impose high costs on the public by harming people and by requiring expensive cleanup measures. In addition, costs may result from toxic landfill facility siting conflicts. Communities may object to nearby disposal sites, and property values may decrease adjacent to real or potential sites.

If manufacturers find that increased pollution control is technologically or economically unfeasible, pulp and paper mills may shut down. Employment in the Green Bay community could be substantially affected. Approximately 40% of the work force in the lower Fox River region is used by the paper industry; their unemployment could affect the region by imposing (a) temporary costs to the public for unemployment compensation; (b) temporary loss to society due to unemployment of capital and labor; (c) financial loss to industry shareholders; and (d) greatly increased consumer prices for paper products.

Municipal sewage treatment plants-Further limits to allowable levels of toxic discharge from municipal sewage treatment plants will increase the cost of these services by creating a demand for more research and technological modifications. If pulp and paper mills discharge through municipal systems, industry would also be affected.

Potential benefits-Not surprisingly, costs of toxic management do not necessarily accrue to the same users or groups of users who benefit the most from toxics control. When generators of toxics are required to assume the costs of meeting toxic discharge effluent standards, then commercial and sport fishermen, for example, benefit from increased marketability and fewer restrictions on fish consumption. Users who perceive the waters as safer and cleaner, such as swimmers and recreational boaters, may increase their activities. Bay shoreline and tributary residents may realize property value increases as well.

Hydraulic Engineering

Recommendations for hydraulic engineering include dams, dredging, shoreworks, entrainment and impingement, and landfills. Implementation of these recommendations, however, requires consideration of the factors discussed on pages 34 and 41; therefore, only the broadest marginal benefits and costs are discussed below.

Potential costs and benefits-Although the costs of engineering design, construction, and maintenance of hydraulic engineering structures would be borne primarily by taxpayers, the public benefits would be high. Wildlife habitat areas, for example, will increase with construction of dredge spoil islands and dikes, which will affect enjoyers, waterfowl hunters, and sport and commercial fishermen. At the same time, these islands will allow reduced wind stress which will have the effect of decreasing nutrient and toxic recycling in lower bay waters. If designed to incorporate toxic disposal fills, this method has the added benefit of reducing environmental harm from these substances, although it may also cost more than some other disposal methods.

The high cost of artificial island building will only be tolerated if the following needs coincide:

1) a critical need for protection of a shore or water area;
2) a pressing need for more recreational space, including shelter for small boats; and
3) a need to dispose of solid wastes (dredge spoils) in large volumes.

It appears that all three needs coincide in the case of the bay.

Fish management costs may actually decrease because of program efficiency. For example, carp control effected through entrapment, improved yellow perch spawning grounds adjacent to dredge spoil islands and dikes, and. establishment of macrophytes would result in benefits to fishermen, fish consumers, and enjoyers.

Construction of harbors and marinas will potentially benefit recreational boaters, enjoyers, and sport and commercial fishermen.

FISHERY MANAGEMENT

The fishery is, in many respects, the barometer of the Green Bay ecosystem. An improved fishery will, by definition, incorporate many of the benefits and costs outlined previously. In addition, some benefits and costs accrue to fish stock manipulations and carp control. Payers and receivers coincide more closely for fish management than with some other rehabilitative strategies.

Benefits and costs-Anglers, fish consumers, and commercial fishermen will directly benefit from fish stock manipulations. In addition, there will be some new costs and benefits associated with researching and establishing markets for currently underutilized species such as white suckers and burbot.

Reducing the number of carp can reduce the resuspension of sediment-asociated nutrients and toxics. Anglers and consumers, as well as a much larger indirect audience, will benefit from carp control.

Regulation of the yellow perch fishery will primarily benefit commercial fishermen, who are also representatives of consumers in an economic sense. Efforts to reestablish a walleye fishery in lower Green Bay would initially benefit sport fishermen, with the hope of eventually benefiting the commercial fishery as well. Similarly, sport and commercial fishermen could benefit from species diversity as a result of reestablishing white bass, northern pike, and crappie populations.

THE INSTITUTIONAL CONTEXT

A wide array of government agencies and institutions become involved in managing natural resources. Our traditional governmental units have operated on three tiers: the federal, state, and local levels. Their jurisdictions are determined by political boundaries. These political boundaries too often artificially divide naturally functioning environments. To meet the ensuing difficulties created by artificial divisions, new layers of institutions have been formed to encompass geographical areas such as watersheds or drainage basins. These institutions function on an international, multistate or multicounty basis. The Great Lakes basin has a complex array of political units that have structured a complex mosaic of agencies and institutions with authority and responsibility for the Great Lakes and related land resources.

Any ecosystem rehabilitation strategy devised for application on the Great Lakes must take account of the institutional arrangements necessary for implementation. The Great Lakes ecosystem rehabilitation study group addressed this issue by:

- developing a preliminary list of agencies or institutions that may play a role in Green Bay rehabilitation;
- identifying functional roles of agencies and institutions;
- conducting a *preliminary* identification of government agencies or institutions and their formal responsibilities for dealing with different elements of a strategy specific to lower Green Bay;
- conducting a survey of agency administrators to assess perception of their roles specific to the management of critical stresses in lower Green Bay;
- integrating this information in the form of a stress/institution matrix for the lower Green Bay ecosystem.

These activities were designed to help identify those agencies which would have to be involved to implement the elements of the rehabilitation strategy for the geographical area of concern. The inventory of agencies and institutions can be used as a guide to the formal standing institutional structure through which ecosystem rehabilitation measures have to be devised and implemented. The findings and recommendations emanating from this institutional study must be considered preliminary and should be further verified through actual implementation efforts and activities.

MATRIX DEVELOPMENT - AGENCIES AND THEIR ROLES

The preliminary list of agencies and institutions which affect the lower Green Bay ecosystem through their activities numbered well over 40. For the purpose of matrix development, both the number of agencies and the number of stresses addressed were reduced. Twenty-one agencies and institutions which have direct responsibilities for managing the lower bay and its environs were selected for analysis. The critical stresses were reorganized into chemical, biological, and physical categories with which agencies could more readily identify.

Each agency or institution was contacted and, in most cases, a personal interview was conducted to determine the extent of their involvement with the bay and the types of management functions they performed. Management roles recorded in each matrix cell (Tables 10, 11, 12) reflect both statutory and perceived responsibilities and were classified as follows:

M - Direct management or manipulation of the system. This refers to active resource manipulation or environmental management practices carried out by agencies (i.e. stocking, dredging, wastewater treatment). It is viewed as separate from the more general management roles of administration of programs or regulations.

TABLE 10. Management roles of binational and federal institutions in ecosystem management.

	International Joint Comm.	Great Lakes Fishery Comm.	Great Lakes Basin Comm.	Great Lakes (Compact) Comm.	EPA	Soil Conservation Service	Army Corps of Engineers	Fish & Wildlife Service	Nat. Marine Fisheries Ser.	Fed. Energy Reg. Comm.
PCBs	**S**	**S**	**PRS**	**S**	**EPR FS**		**MER S**	**RS**	**FS**	
Other toxics	**FS**	**S**	**PRS**	**S**	**EPR FS**		**MER S**	**RS**	**FS**	
BOD loadings	**S**	**S**	**PRS**	**S**	**EPR FS**		**MER S**	**RS**		
Phosphorus	**S**	**S**	**PRS**	**S**	**EPR FS**		**MER S**	**RS**		
Suspended solids	**FS**	**S**	**PRS**	**S**	**EPR FS**		**MER S**	**RS**		
Nonpoint source		**S**	**PRS**	**S**	**EPR FS**	**MPR SS**		**RS**		
Sport fishing		PRF S	**S**	RS	RFS		**MPR S**	RFS		MP
Commercial fishing		PRF S	**S**	RS	R		**MPR S**	RS	RFS	
Stocking		PRF S	S	RS				MRF S		
Entrainment/impingement		S	S	S	EPR FS			RS		
Exotic species		PRF S	s	s				**MPR FS**	RFS	
Dams	ERS	PFS	S	RS		**MPR FS**	**MEP RF**	RS		MEP RS
Shoreworks		S	RS	RS			**MEP RFS**	RS		
Dredging	RS	S	RS	RS	EPR **S**		**MEP RFS**	RS		
Landfill	R	S	S	S	EPR FS		MEP RFS	ERF S		

TABLE 11. Management roles of regional and local institutions in ecosystem management.

	Wisconsin Coastal Mgmt. Program	Sea Grant Institute	Bay-Lake Regional Planning Comm.	Fox Valley Water Qual. "208" Planning Agency	Lake Michigan Federation	Brown County Regional Plan. Comm.	Local Zoning Authority	Green Bay Metro. Sewage District	Local Sanitary Districts	Soil and Water Conservation District
PCBs	PRF S	RFS	S		RS			MPR FS	M	
Other toxics	PRF S	RFS	S		RS			MPR FS	M	
BOD loadings		RFS	S	PRS	RS	S		MPR FS	MP	
Phosphorus		RFS	S	PRS	RS	S		MPR FS	MP	
Suspended solids		RFS	S		RS			MPR FS	MP	
Nonpoint source	PRF S	RFS	S	PRS	RS	PS	EPS			MEP RFS
Sport fishing	RFS	RFS	S		R	S				
Commercial fishing	RFS	RFS	S		R					
Stocking	RFS	RFS			R					
Entrainment/impingement					R					
Exotic species		RFS	S		R					
Dams	S		s	PS		S	M			MRF S
Shoreworks	S		S			PS	E			
Dredging	S	RFS	S	PS		S	E			S
Landfill	S		s	PS		S	E			S

TABLE 12. Management roles within Wisconsin's Department of Natural Resources.

	Bureau of Water Quality Mgmt.	Bureau of Waste Water Mgmt.	Bureau of Fish Mgmt.	Bureau of Solid Waste Mgmt.	Office of Intergovernmental Programs
PCBs	EPRS	ERS	RS	EPRS	F
Other toxics	EPRS	ERS	RS	EPRS	F
BOD loadings	EPRS	ERS	S		F
Phosphorus	EPRS	ERS	S		F
Suspended solids	EPRS	ERS	S		F
Nonpoint source	PRS		S		F
Sport fishing			EPRS		
Commercial fishing			EPRFS		
Stocking			MEPRFS		
Entrainment/impingement			S		
Exotic species			MEPRS		
Dams	S		S		
Shoreworks			S		
Dredging	S	E	S	PRS	
Landfill			S	EPRS	

E - Enforcement of regulations. This includes the development of regulations under statutes, establishment of standards and limits, administration of permit systems, and various other related monitoring and enforcement activities.

P - Planning function. This refers to longer-range sectoral and/or spatial (regional) planning activities and statutory planning responsibilities.

F - Funding responsibility. This refers to administration of subsidies and grants to other agencies or groups for carrying out activities related to some remedial or developmental program. Funding may be applied toward other management functions such as research, data collection, planning studies, or support activities.

R - Research and data collection. Development and administration of research or coordinated data collection programs where information is made available to the public.

S - Supporting activities. This refers generally to a variety of activities which often support other management roles and includes coordination, advisory services, public information, and education programs.

MATRIX ANALYSIS

One way of summarizing the institutional interactions with the Green Bay ecosystem is to determine the distribution of the various kinds of functions undertaken by institutions across all of the stress categories. They are listed in descending order of activity level as follows:

Support activities = 173
Research and data collection = 107
Planning function = 62
Funding responsibility = 61
Enforcement of regulations = 36
Direct management = 32

This suggests that about one-seventh (14%) of the functions performed are represented by definitive activities of regulation enforcement and direct manipulation while support and research activities account for nearly 60%.

Another way of summarizing the institutional context is to examine the frequency with which agencies or institutions address the four specific ecosystem stress categories. Agency interactions with stress categories were determined by combining the following stress matrix cells:

TOXICS = PCBs and other toxics
NUTRIENTS = Phosphorus and Nonpoint Sources

SS & S = Suspended Solids and Sediments
FISHERY = Commercial Fishing, Sport Fishing, Stocking and Exotic Species

Frequency values were derived by calculating the proportion of agencies which addressed a stress category in any way (Table 13, column 1) and the proportion of agencies which addressed a stress category by way of a particular function (remaining columns).

TABLE 13. Frequency of agency involvement (by functional role) with critical stress categories.

	Overall Agency Involvement	Direct Management	Enforcement	Planning	Research	Funding	Support
TOXICS	.71	.14	.14	.23	.42	.33	.67
NUTRIENTS	.90	.24	.19	.52	.57	.38	35
ss & s	.90	.24	.24	.52	.57	.38	.85
FISHERY	.67	.19	.05	.24	.48	.33	.57

The resulting frequency values reveal that NUTRIENTS and SS & S are being addressed by more agencies and through a greater range of management functions than are TOXICS and FISHERY stresses. Additionally, relatively few agencies have direct manipulation or enforcement functions while many agencies claim support and research or data collection functions.

An activity level for ecosystem management (Management Index) was derived for each agency or institution by summing the management roles in all matrix cells for a given agency or institution. These management indices are recorded by agency or institution in descending order of activity:

WI DNR	61
U.S. Army Corps of Engineers	51
U.S. E.P.A.	47
U.S. F. & W.S.	38
WI Sea Grant Institute	33
Great Lakes Basin Comm.	29
Great Lakes Fishery Comm.	28
WI Coastal Mgmt. Program	25
Green Bay Metro. Sewage District	25
Great Lakes Comm.	20

Lake Michigan Fed.	17
Fox Valley Water Quality Planning Agency	15
International Joint Comm.	14
Bay-Lake Regional Planning Comm.	13
Soil and Water Conservation District	12
Soil Conservation Service	10
National Marine Fishery Serv.	10
Brown Co. Regional Planning Comm.	10
Local Sanitary Districts	8
Local Zoning Authority	7
Fed. Energy Reg. Comm.	7

This rank order of activity levels reveals generally that those agencies or institutions farthest from the geographic area of concern have a higher level of engagement with the critical stresses affecting Green Bay than do those agencies more immediately proximal to the problem. This may not be surprising but it does indeed beg the question of who must be involved in ecosystem management of lower Green Bay.

SYNTHESIS

Analysis of the institutional framework for coping with the identified critical stresses of lower Green Bay suggests:

- — That all stresses are being addressed;
- — That TOXICS and the FISHERY are receiving less emphasis than NUTRIENTS and SUSPENDED SOLIDS;
- — That enforcement activities related to fisheries management are less frequent than enforcement activities related to other critical stresses;
- — That a relatively small proportion of agencies are involved with the definitive management activities of regulatory enforcement and direct management;
- — That in many cases direct management and regulatory functions are housed within separate agencies;
- — That local and regional agency activity in the overall management of the Green Bay ecosystem is far less pronounced than federal or state activity.

The approach and analysis suggests but falls short of clearly defining the agencies that must be involved in rehabilitation of lower Green Bay. On the one hand those agencies participating in the definitive activities of enforcement and direct management and also those with the highest activity values, which include WI DNR, U.S. Army Corps of Engineers, U.S. E.P.A., and the U.S. F. & W.S., might logically be the mainstay of ecosystem rehabilitation. On the other hand this "priority ranking" would tend to neglect intermediate players such as WI Sea Grant Institute, Great Lakes Fishery Commission, and Green Bay Metro Sewage District let alone those lower ranking regional and local agencies such as the Bay-Lake Regional Planning Commission, Lake Michigan Soil and Water Conservation District, Brown County Planning Commission and Local Zoning Authorities.

Although the institutional analysis does not prescribe the definitive institutional arrangement for successful ecosystem management and rehabilitation, it does reveal that effective management of the Green Bay ecosystem and the fishery will depend upon a balanced involvement of agencies and institutions. Furthermore, the private sector including identified user groups must also be involved.

Although numerous management activities are identified, the agencies and user groups associated with the bay have a long history of limited cooperation and coordination. As a result, the present ad hoc policies do not promote rehabilitation. The current momentum must be redirected toward a management consensus based upon sound ecological principles.

Governing by consensus is very difficult. It depends upon broad-based understanding of a problem and the alternative solutions to that problem. It also depends upon long-term commitment by public and private sectors to coordinate the use of resources necessary for rehabilitation. Further, it depends upon significant local citizen involvement which includes frequent contact with local elected officials as well as elected representatives in state and federal government.

The limitation to rehabilitation of the Great Lakes appears to be more of an entanglement of institutional arrangements than knowing what has to be done in an ecological sense. The challenge is to create a new level of understanding, integration, and cooperation which will provide for the optimal level of bay uses including the perpetuation of a viable, diverse and sustainable fishery.

APPENDIX A

Criteria and Procedure for Identifying Cells Requiring Decision Resolution[a]

ORIGINAL MATRIX

0	3	0	0	2	2	1	1	0	1
1	0	3	2	0	1	2	1	1	0
?	0	0	1	1	0	0	1	2	2

DECISION — LEANING — EMPTY

DECISION → REVISED MATRIX

LEANING, EMPTY → Resolution of leaning and empty cells → ORIGINAL MATRIX

[a]Procedure for making the "revised" matrix on the basis of the degree of consensus between the three separate groups of workshop participants filling out the "original" matrix. After the "revised" matrix was created, we resolved the leaning and empty cells in the "original" matrix by group discussion and voting.

EPILOGUE

One year and three months have passed since the efforts above were put down in ink. At this point we are stimulated to ask yet a few more questions. What motivated us and our many colleagues to participate in Green Bay workshops I, II, and III? Has the exercise been useful in helping mobilize a rehabilitation effort for lower Green Bay? And, finally, what has happened at Green Bay since we finished this document?

In looking back at the workshops, we find that they were perhaps the most enjoyable and stimulating activities in which we have ever participated. There was a sense of forward movement, a sense of beginning to understand the nature and demands of a comprehensive rehabilitation plan, a sense of purpose, and a sense of community. Many of us with our specialized backgrounds found ourselves exposed to ideas and concepts new, but exciting. We knew we were being idealistic, or perhaps creatively realistic about what was required and what could be done to help rehabilitate Great Lakes ecosystems. We learned a great deal more than we offered. The activity was positive rather than restrictive. The approach held promise for better futures and we were caught up in the excitement of the purpose, the process, and the intellectual activity.

THE FUTURE

Even after a plan of recovery is identified, rehabilitation of natural systems takes time. The above plan is preliminary; it will change. We believe it will be a conceptual model that will provide a framework for the people of the Green Bay region to continue to move forward in their rehabilitation of the bay.

In fact, the working draft of this report helped precipitate the formation of a regional task group which has begun to address the problems associated with rehabilitation. The fact that the group has a broad spectrum of public agency, public institution and private sector representation and is coordinated by an existing regional planning agency (Bay Lakes) suggests that some effective transfer of the concept of rehabilitation has already occurred. The group's self designation as "Future of the Bay-Technical Advisory Committee" (FOB-TAC) is heartening for it connotes a positive if not visionary approach to the management of the bay. FOB-TAC has recognized in a working paper the need for a comprehensive and coordinated systems approach which we firmly believe is a step in the right direction. Perhaps of greatest significance is the sensitivity to the need for public support. In this regard, FOB-TAC has moved to establish the first annual "Bay Awakening" conference which is designed to interface the broader public with agency activities and issues surrounding bay rehabilitation. The first "Bay Awakening," scheduled for October 1982, may serve as a stepping stone to the successful rehabilitation of Green Bay. This evidence of direction and coordinated movement marks the beginning of a consensus management process-should we expect more?

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