Research Needs for Green Bay: Proceedings of the Green Bay Research Workshop

University of Wisconsin-Green Bay
September 14-16, 1978

Editors
H.J. Harris and
Victoria Garsow

RESEARCH NEEDS FOR GREEN BAY

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SEA GRANT RESPONSE

ACKNOWLEDGEMENTS

It is somewhat presumptuous to list ourselves as editors of this report. It is done primarily to establish accountability for whatever errors appear in the proceedings and for any inconveniences encountered by agencies and individuals who participated in the workshop. Whatever credit is due must be attributed to conference participants, authors of manuscripts and members of the Green Bay Program Steering Committee. Conference participants are identified in Appendix A and authors of the manuscripts are identified in the body of the proceedings. Members of the Steering Committee are listed below.

Dr. Daniel Bromley, Professor, UW-Madison
Dr. Joseph Delfino, Associate Professor and Head, Environmental Sciences Section, State Laboratory of Hygiene, UW-Madison
Mr. Ernest Ehrbar, Northeast District Director, UW-Extension
Ms. Lynn Frederick, Advisory Services Field Agent, UW Sea Grant College Program
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Dr. H.J. Harris, Associate Professor and Coordinator of Sea Grant Green Bay Subprogram
Mr. George Mackin, Paper Manufacturing Consultant
Dr. Clifford Mortimer, Professor, UW-Milwaukee
Dr. Paul Sager, Associate Professor, UW-Green Bay

H.J.H.
V.G.

PREFACE

These proceedings record the written contribution of several authors and reflect the active participation of nearly one hundred individuals in an intensive workshop atmosphere held on the University of Wisconsin-Green Bay campus from September 14th through September 16th, 1978. The events leading up to the Green Bay Research Workshop are briefly reviewed in Dr. Robert Ragotzkie's introductory remarks and will not be presented here.

However, I would point out to the users of this document that these proceedings represent not only a product but part of a planning process as well. In this regard a portion of the document is futuristic in the sense that the success of the workshop cannot be adequately evaluated until there is sufficient time to act on the resulting recommendations. For those who may in the future be interested in evaluating the effectiveness of the workshop, an accounting of the goals of the workshop and its design may be of significance. In any event an understanding of the design of the workshop and a summary of the task group deliberations should be useful to most users in gaining the most from these proceedings.

Workshop Objectives

The overall goal of the Green Bay Program is to develop a research framework where cooperative efforts between researchers, will result in an improved comprehension of the Green Bay Ecosystem and ultimately serve as a sound basis for resource management decisions.

In working toward this goal we recogize that the research framework cannot be developed in a vacuum; it must be a participatory process if it is to be sustained and research results applied. It is also clear that there is a serious lack of communication between agencies engaging in research on Green Bay and an even more serious lack of communication among individuals performing research or proposing to undertake research. In addition to these communication barriers it is also evident that project investigators and potential researchers need a clearly identified (mutually understood) framework within which their own creative research interest can be channeled. The Green Bay Research Workshop was conceived as one means of addressing the problems above and taking the first step toward our program goal.

The specific objectives of the workshop are:

- Provide a vehicle for critical review of selected areas of past research.
- Stimulate the existing and potential pool of researchers to focus efforts on Green Bay in a coordinated and cooperative mode.
- Solicit priority research needs on Green Bay from representatives of universities, public agencies and industry.
- Foster the development of a cooperative research effort between the University of Wisconsin Sea Grant and Michigan Sea Grant Programs on Green Bay.

Workshop Structure

With these objectives in mind the Green Bay Program Steering Committee* arrived at a somewhat unique design for the workshop. In addressing the need to update our present understanding of the Green Bay Ecosystem, four areas of interest were selected for review, three of which were completed as papers by individual authors and were distributed to all participants prior to the actual workshop.

A mix of representatives from academia, government and industry were sought as workshop participants. The actual attendance record (Appendix A) reveals that researchers from seven different universities and two states (Michigan and Wisconsin) participated. Individuals from at least eleven different public agencies attended the workshop as well as several representatives from the industrial sector.

The agenda for the workshop (Appendix B) included two overview papers intended to further orient and stimulate participants. Workshop participants were assigned to one of six task groups prior to the workshop. The six task groups were: Trophic Interactions, Environmental Contaminants and Human Health, Water Movement and Mass Transport, Water Use Implications for Green Bay, Influences of Land Use on the Bay, and Fisheries. Following the presentation of the overview papers, each task group was charged with identifying the most critical research needs in their area and with developing a two to three page report in which research priorities would be identified and supported with a brief rational.

Task groups met for the better part of one day and developed a preliminary report which was shared with the other task groups at a plenary session on the afternoon of the 15th. Task group reports were finished Friday night and Saturday morning. The Task group reports are included as they were received from the individual task group leaders. The lack of uniformity between task group reports reflects the fact that each task group took a different approach to the problem of identifying research priorities.

*See acknowledgements

The task group reports and recommendations will provide, in part, the basis for research programming over the next several years.

Following the workshop the Green Bay Program Steering Committee reviewed the recommendations of each task group. The Steering Committee analyzed the content of the reports with respect to:

- 1st and 2nd order connection (linkages) between task group recommendations (i.e. where are they strongly supportive?; where are they moderately supportive?; where are they contradictive?)

- ten year time frame - i.e. (what should be done tomorrow, next two years, next five years, etc. - phased program)

- distinct differences or contradictions in the priorities or time references of the recommendations

The Steering Committee evaluated separate recommendations of each task group against the criteria of the two-way matrix outlined below:

<u>Comprehension of System</u>

<u>Relation to Policy</u>	Essential	Helpful	Marginal
Immediate Use	1	2	3
Eventual Use	4	5	6
Little Use	7	8	9

Those research topics which were assigned to cells 1 and 2 represent priority research needs which can and should be undertaken as soon as possible. In effect, the Steering Committee set out to identify research topics appropriate for the upcoming interim call for proposals (December 1978). This action by the committee is viewed only as the first step in the development of an operational framework for a sequentially coherent research program.

The research topics (areas) recommended for the interim call were:

- Sources of Toxics/Identification
- Water Quality Surveillance and Monitoring
- Sediment Water Interactions (phosphorus, contaminants, internal nutrient budget, transport)
- Mean circulations, large eddies and gyres, chemical tracing
- Groundwater Transport Systems
- Surface Transport Systems

H.J.H.

INTRODUCTORY REMARKS-ROBERT A. RAGOTZKIE

Welcome to participants.

We appreciate your willingness to take time from your busy schedules to attend and participate in the Green Bay Research Workshop.

The purpose of the workshop is to develop a research plan which deals with the resources and overall environment of the bay of Green Bay, its coasts and the land surrounding this Bay.

As most of you know, the subject of Green Bay is not new to Sea Grant. For a number of years the Sea Grant Program sponsored a "Green Bay Program." The culmination of this early program was the publication of the book "The Green Bay Watershed, Past/Present/Future" by Gerry Bertrand, Jean Lang and John Ross. This book summarized much of the Sea Grant work on the Bay along with a great deal of information derived from other sources. The report considered very carefully the state of our knowledge of the Bay and based on this, identified the main gaps in this knowledge base. The report went on to define rather specifically what problems and issues should receive attention.

A little over a year ago, at a planning retreat a team of university people under the leadership of Dan Bromley took on the task of designing a new Green Bay Program. Using their plan as a blueprint we began the new Green Bay Program last year. We were extremely fortunate in persuading Bud Harris to take on the job of Program Leader. A Steering Committee was set up and the program was underway. Bud Harris and the Steering Committee decided early on that more detailed planning was needed and that we should begin to involve the Green Bay community as well as the Michigan Sea Grant Program as soon as possible. This workshop is a major step in that process.

Shortly, after you have induldged Bud Harris and me in our opening messages, you will hear from two experts on the Great Lakes and Green Bay in particular. First, Al Beeton, formerly of UW-Milwaukee and now Director of the Michigan Sea Grant Program will give you his perception of the state of the Bay, particularly its ecosystem. Following him, John Ross, one of the authors of the Green Bay Report and Director of the Wisconsin Seminars on Resource Environmental Systems will discuss the people aspects of the Green Bay system.

You have already received considerable background material for the workshop. I especially call your attention to the specific objectives of the workshop.

These along with the format of the workshop and your charge will be discussed by Bud Harris, our convener and leader.

Before expressing my own hopes and challenge for the workshop, I want to express my sincere appreciation to Bud Harris and Vicky Garsow and their staffs who did so much to make this meeting possible and to ensure its success. In addition I want to recognize and say thank you to the people who took time from their busy summers to prepare review papers for the workshop. To Jack Day, Basil Sharp, Dan Bromley and Cliff Mortimer--thank you for your important contributions.

Let me also express for myself and for all of you, a hearty thank you in advance, to Chancellor Weidner and the Green Bay campus for their gracious and generous hospitality in hosting this workshop. Such hospitality has become a hallmark of UW-Green Bay and we appreciate it.

Let me now comment briefly, very briefly, about my hopes for the workshop and issue a challenge. I am a strong believer in meetings such as this for the development of sound and effective programs for research and service by the university. It is essential that our program planning include the very best talent and the widest possible spectrum of knowledge--whether from the university community, from local and state and federal governments, from the public, or from industry. I believe that Bud Harris has done an outstanding job in assembling exactly this kind of mix.

I have no doubt whatsoever, that at the conclusion of this workshop we will have taken another major step forward in creating a comprehensive and productive program to improve the utilization of Green Bay's resources and enhance its environment. I further have no doubts that you and we will find the people to carry out this program. I thank you in advance for the critical contribution you are going to make.

In your deliberations I would urge you to deal with the issues and problems as you see them and to design a program to address them regardless of the level of effort or cost required. Certainly the resources of Sea Grant are limited, but I submit that the resources from all sources, whether they be federal, state, local or regional, are less limited. A sound program that can show the way and that has a good chance of success will attract such support.

One aspect of the program was omitted from the workshop agenda. That aspect is education. There is no task group to deal with education. This is as it should be since all of you are experts on education and none of you would feel comfortable about delegating that subject to others.

Nevertheless, education must be a keystone of any Green Bay Program if any real impact is to be made. Research results, however erudite or brilliant, are of little value if they are not translated into policies and options for resource management and environmental enhancement, and then communicated to the people and institutions that need to know.

Therefore I ask that as you develop your plans and recommendations that you also consider and add an education and communication dimension. At the very least, three audiences ought to be addressed:

1. University students who are our future leaders, educators, and decision makers.

2. The general public and particularly community leaders who must make the decisions on what to do and then pay the cost; and

3. Officials of local and state government who must carry out the policies and management options.

Again I thank you all for coming. Good luck in the next two days.

REVIEW AND POSITION PAPERS

WATER MOVEMENT, MIXING, AND TRANSPORT IN GREEN BAY, LAKE MICHIGAN

A review with speculations prepared for the "Green Bay Research Workshop": University of Wisconsin Sea Grant College Program, 14-16 September 1978.

by C.H. Mortimer, Center for Great Lakes Studies, University of Wisconsin-Milwaukee

Introduction and Contents List

Based on scanty observations, on analogies with other lakes, and with limited recourse to models, I attempt to describe the properties of the physical stage upon which Green Bay's biological plays are enacted and for which management decisions have to be made. An earlier report (Bertrand et al. 1976) summarizes fairly completely the not very extensive published work on the physical, chemical, and biological characteristics of the Bay and provides a comprehensive bibliography. Here I select those characteristic features of the physical stage deemed critical for understanding the biological play and for good design of management strategies. Where observations are lacking, I fall back on speculations to suggest where new research is needed.

The review is presented in six sections as follows:

Morphometry and Water Budget

Somewhat misnamed as a bay, Green Bay is a relatively shallow gulf connecting into the northwestern part of Lake Michigan (Fig. 1). Morphometric estimates--made in connection with seiche mode calculations based on sections shown in later Figure 6--yield: a length of 193 km (120 miles) along a medial track running NE from Green Bay Harbor entrance to the head of Big Bay de Noc; a water surface area of 4,520 km^2 (1640 sq. miles); and a volume of about 67 km^3 (16 cubic miles). These estimates--assembled with others in Table 1--respectively represent 7.4% and 1.4% of the total area and volume of Lake Michigan including Green Bay, and they correspond to a mean width of 22 km (14 miles) and a mean depth of 15.8 m (52 ft.).

Table 1. Morphometry of Green Bay, Lake Michigan (See Fig. 1). (Except as otherwise indicated in footnotes, the estimates were made in the course of seiche calculations in Mortimer, 1965).

Area:	water surface (A)	4250 km^2	1640 mi^2
	land catchment (C)*	40500 km^2	15625 mi^2
Ratio:	land/water(C/A)	9.53	
Length:	(L, see text)	193 km	120 mi
Mean width (A/L)		22 km	14 mi
Volume (V)		67 km^3	16 mi^3
Depth:	mean (V/A)	15.8 m	52 ft
	maximum (D in Fig. 1)	54 m	176 ft
Cross-sectional area of "mouth" (section PQ in Fig. 1)		0.52 km^2	
Mean discharge of inflowing rivers (Total T) ‡		336 $m^3 s^{-1}$	11900 cfs
Basin (gulf) "emptying time" (V/T, see text)		6.0 yr	

*Bertrand et al. (1976)

‡Table 2 values adjusted pro rata to whole catchment area; based on data in Great Lakes Basin Commission (1976).

The deepest region--maximum depth 54 m (176 ft.) 7 km WNW of Washington Island(D in Fig. 1)-- is not far from the gap through which the gulf opens into Lake Michigan through five main passages ranging in width from 2.2 to 7.1 km (1.4 to 4.4 miles) all but one being deeper than 30 m. The total cross-sectional area of the "mouth" (Section 13 in Fig. 14 of Mortimer 1965) is 0.52 km^2. Therefore substantial exchanges of water occur between the gulf and the main lake basin. Exchanges through the Sturgeon Bay Canal are relatively minor.

The heads of the northern bays and the southwestern portion of the main gulf (often called the "Inner Bay") are very shallow. Proceeding from those regions toward the gulf mouth, and ignoring topographic complexities around islands and reefs, the bottom contours exhibit a relatively regular depth increase. There are a few isolated sub-basins. For example, the point of maximum depth at D lies in a narrow trough of about 6 miles in length bounded by the 140 ft. (43 m) contour. Another slight depression, extending from Green Island to Monument Shoal, is bounded by a closed 105 ft. (32 m) contour and has a maximum depth of 113 ft. (35 m) near the Island (G in Fig. 1). The southern part of the gulf (the Inner Bay) and the side arm, Sturgeon Bay, slope into this depression, but the slope is very gradual in some areas. Another depression (W in Fig. 1) is a narrow trough (also bounded by the 32 m contour) lying 1.5 miles (2.4 km) NE of Whaleback Shoal. Its maximum depth is 140 ft. (43 m) and its main catchment basin lies in the northern part of the Bay.

The total land area draining into the gulf is estimated at 40,500 km^2 (15,625 sq. miles, Bertrand et al. 1976) which yields a land/water area ratio of 9.5. The corresponding ratio for Lake Michigan as a whole is much less, 2.04 (Co-ordinating Committee 1977).

Total river discharge into the gulf—long term average and range—can be estimated relatively accurately because, as Table 2 shows, nine-tenths of that discharge is contributed by six rivers, the gaged areas of which add up to 83% of the total catchment. Monthly mean flows vary over a fivefold or greater range in most years, with a peak flood in April and lowest flows in August-September. The year-to-year variability is also considerable (see later Figure 17 for the Fox River).

Table 2. River discharge into Green Bay, Wisconsin.
(Columns 1 and 2 from Great Lakes Basin Commission 1975; columns 3 and 4 from Great Lakes Basin Commission 1976; data derived from U.S. Geological Survey 1971)

River	Drainage area km^2	Gaged area km^2	Discharge, $m^3 s^{-1}$ Range	Mean
Escanaba	2384	2255	3-297	25
Ford	1213	1166	0.7-215	10
Menominee	10757	9824	5-935	88
Peshtigo	2994	2914	2-277	24
Oconto	2418	1757	3-238	16
Fox-Wolf	16700	15941	4-680	118

Pro rata application of the total mean discharge in Table 2 to the whole catchment area (40,500 km^2) yields a total mean rate of 336 $m^3 s^{-1}$ as catchment run-off into the gulf. To arrive at a mean rate of total water input, contributions from mean precipitation onto and evaporation from the water surface must be added and subtracted, respectively. Measurements of these contributions are not available for Green Bay; but it is reasonable to take Lake Michigan estimates as representative: i.e. a "perimeter precipitation" of 78 cm yr^{-1} and an annual evaporation of 65 cm yr^{-1}, derived from Tables 4-13 and 4-15 respectively (Great Lakes Basin Commission, 1976). The difference of +13 cm yr^{-1} on a Green Bay water surface of 4250 km^2 is equivalent to an influx rate of 17.5 $m^3\ s^{-1}$. This, added to the land run-off (336 $m^3\ s^{-1}$), yields a total supply rate of 354 $m^3\ s^{-1}$, which makes up about one quarter to the mean outflow of Lake Michigan (estimated at 1500 $m^3\ s^{-1}$ through the Straits of Mackinac, Great Lakes Basin Commission, 1976). The supply rate of 354 $m^3\ s^{-1}$, divided into the gulf volume, yields an emptying time of 6.0 yr. The corresponding time for the whole of Lake Michigan, including Green Bay, is much longer, 104 yr.

But, I hasten to add, the concept of "emptying time" is a misleading abstraction when applied to an open-mouthed basin in relatively free exchange at its mouth with an open lake or ocean. More realistic estimates of water (and pollutant) residence times are provided by the simple mixing models described in a later section.

Fluctuations in Water Level

As part of Lake Michigan, Green Bay follows the seasonal and longer-term changes in level of that Lake. The annual range is about one foot and, over the 118 years of continuous record, the highest monthly mean was 581.9 ft. (177.4 m) above sea level (International Great Lakes Datum) in June 1886 and the lowest monthly mean was 575.4 ft. (175.4 m) in March 1964, a range of 2 m. In recent years, August 1974 came within 0.9 ft. of the 1886 maximum.

Turning from monthly means to hourly readings, striking differences between the behavior of Bay and Lake emerge. Levels in the Bay commonly oscillate with much greater amplitudes than those in the main basin, and with a preferred periodicity in the range 9 to 12 hr. An example of this "sloshing" or seiche response, representing amplification through resonance, is illustrated in the third panel in Figure 3. The small-amplitude 9-hour seiche oscillations at two main-basin stations (Mackinaw City and Holland, out of phase with each other as characteristic of the first main-basin mode) are accompanied a much larger oscillation (broken line) of the same period at Green Bay City. This amplified response is a consequence of the fact that the period of one of the free modes of oscillation of the Bay (or rather of the combined Bay/Lake) is close to 9 h, calculated in fact to be 10.8 h by Mortimer (1965) and 10.37 h by Rao, Mortimer and Schwab (1976) taking Earth's rotation into account (see later Figure 5). There is a similar resonance--in this case a forced response--with the semidiurnal tide-generating force (12.4 h period) so that typical power spectra of water level fluctuations in Green Bay (Figure 4) show, not only a large concentration of energy in a broad spectral peak covering the 9 to 13 h range, but also peak summits of 12.4, 11 and 9 h. These respectively represent the tidal resonance, the free (first mode) oscillation of the Bay/Lake system, and the first mode of the main lake basin. There is also a small resonant response (peak 2 in Fig. 4) corresponding to the second Bay/Lake mode.

The computed structure of the first and second Bay/Lake modes is illustrated in Figure 5. Almost all the activity of these particular modes, in terms of seiche amplitude, is confined within the Bay, with maximum fluctuation at Green Bay City. Minimum amplitude occurs just outside the gulf mouth, not at a nodal line which would be characteristic of a bay seiche without rotation, but in an amphidromic (rotating phase) pattern imposed by Earth's rotation. Only at one point—the amphidromic point—is the seiche amplitude always zero in the Figure 5 model.

Details of this remarkable double resonance, fascinating though they are, need not concern us here. (The phase relationships of the Bay seiche with the tide and with the 9 h Lake Michigan seiche are illustrated in Figure 4; and the complex dynamical conditions at the mouth of the gulf are analyzed by Heaps 1975). However, we need to estimate the contribution of these motions to the current patterns in various regions of the Bay. Confining our attention to the first gulf mode (the principal one) and neglecting the effects of rotation, we may consider the combined Bay response as being made up of discrete contributions (illustrated by selected episodes in Figure 3) as follows: tide-driven (top panel); main basin seiche-driven (1st and 2nd modes in panels 3 and 4); and the free Bay oscillation (2nd panel). A simple model of the latter contribut ion was constructed using the one-dimensional Defant (1918) method, but not published, in connection with my 1965 study. Some results are illustrated in Figure 6.

Pivotted on a nodal line set at Section 13, the gulf water surface see-saws up and down in simple harmonic motion with maximum amplitude at Section O (Green Bay City) and with a period of about 11 h. The water masses along the gulf also move horizontally to-and-fro. The seiche-induced currents reverse direction at the times of maximum and minimum water level i.e. twice per cycle: and the maximum current speeds are observed every half-cycle, when the water level swings through the equilibrium position. For a seiche of 10 cm amplitude (20 cm range) at Section O (a range commonly seen and commonly exceeded at Green Bay City) Figure 6 displays the along-gulf distributions of seiche amplitude, the half-cycle volume transport through each section, and the corresponding maximum current speeds and water-mass excursions at each section.

Volume transport increases smoothly from head to mouth, but the variation of cross-section area imposes greater variation on displacement and current speed. As expected, these quantities are relatively large near the mouth (the node of the seiche), but they reach a maximum near the constriction imposed by Chambers Island at Section 6. Here we should therefore expect to see the greatest influence of the to-and-fro sloshing action of the seiche. Relatively high current speed levels are also shown throughout the zone between Sections 2 and 6.

Except for the tidal contribution, seiche motion is principally a response to wind stress, acting on the water surfaces of the Bay, or of the main Lake basin, or of both. The one-dimensional procedure which produced Figure 6 can only simulate along-gulf motions. Although these are important, cross-gulf motion and Earth's rotation effects are also part of the picture. Therefore a more elaborate, two-dimensional numerical model (the results of which still await publication—Heaps, Mortimer and Fee, with some of the findings discussed in Heaps 1975)—was constructed to simulate the level changes and current patterns produced by winds, modelled or observed, and by fluctuations in water level imposed by Lake Michigan at the gulf mouth. The latter influence forced us to include in the model, not only the Bay and the immediate environs of the mouth, but also about half of the main Lake basin. The actual topography of Green Bay and the northern half of Lake Michigan was fitted to an array of square "boxes" of 4 km side and with mean depth determined for each. Vertical motions were neglected; the water body was taken as unstratified; the equations of motion, including terms for (quadratic) friction and the Earth's rotation, were integrated from surface to bottom; and an appropriate relationship between wind observations and surface stress was used.

Although a full account of this model and the complexities it has disclosed have yet to be published, some results of water-level simulation are presented here. Corresponding results for currents appear in a later section. Initially level everywhere, the Bay/Lake system was subjected to a variety of model and acting wind stresses, the results of one of which are illustrated in Figure 7. In this case a steady wind of 8 m s^{-1} was directed along the axis of the gulf from mouth to head, with no wind over the Lake in this example. The water level pattern after 40 h shows a slope, which steepens toward the head, and which is made up of a relatively steady component--the wind induced "set up"--and an oscillatory component due to the seiche. Figure 8, which illustrates the corresponding time history of the response, compares an episode of observed water level at Green Bay, Wisconsin, and Menominee, Michigan, with simulations at the nearest model grid points. During the first four hours after onset of wind stress, the simulated levels at Green Bay and Menominee rise to new means at about 8 and 3 cm, respectively, above initial zero. The levels then proceed to oscillate about those means with an approximately 11 h periodicity (indicated by arrowheads). The simulated oscillations at the two stations are nearly in phase with an approximate amplitude ratio of 2:1, in agreement with the amplitude distribution in Figure 6. Similar period, phase, and amplitude relationships are seen in the selected episode of observed level fluctuations, although there was no sudden onset of wind or initial rise in level in this example. The simulated records predict a rapid rise and "overshoot" of level at Green Bay City during the first four hours after sudden onset of strong northerly or northeasterly wind. Thereafter the mean level remains higher than average, with seiche oscillations superimposed upon that mean. Such behaviour is frequently observed.

It is apparent, however, that the gulf seiches are forced into resonant motion, not only by the wind acting on the gulf only, as in Figures 7 and 8, but also by wind action on Lake Michigan and by water level changes imposed at the gulf mouth--produced by tides or by main-Lake seiches. In other words, the picture in Figure 6 of a nodal-line with no level change at the mouth is an over-simplification. The spectra of water-level fluctuations, observed at stations around the Bay and assembled in Figure 9, show that the first and second gulf-mode responses (structures illustrated in Fig. 5) are represented by peaks, not only in the spectra for Green Bay, Wisconsin, and Escanaba, Michigan (E in Fig. 1), but also by smaller peaks at the corresponding frequencies (labelled 1 and 2 in Fig. 9) in the spectrum from the Plum Island Station (P in Fig. 1) situated in the mouth , close to the assumed node (Fig. 6). Heaps (1975) has demonstrated--using the model referred to in connection with Figures 7 and 8--that the fundamental period of the Green Bay oscillation is 9.75 h under the special conditions of a node imposed at its mouth, whereas the observed period of the resonant combined oscillation with Lake Michigan is 10.8 h; and "the water level response at the head of the bay is importantly dependent on whether the response is based on (a) mouth elevation....or (b) the external oscillation in Lake Michigan".

Mixing Models

Because the dissolved salt concentration of the principal inflow to the gulf--the Fox River--is substantially higher than that in Lake Michigan, a salt concentration gradient is maintained along the gulf. Two mixing models have made use of this fact to estimate the rate at which the river water mixes with and is diluted by surrounding

Bay water. The diluting agent is, of course, Lake Michigan water, which enters at the mouth and is subject to southward transport, balancing the northward transport of the river and its excess salt load. Using electrical conductivity as a measure of salt concentration, the concentration field in the Bay can be defined in some detail during a three-day survey, as was done independently during August 1969 by Ahrnsbrak and Ragotzkie (1970, see also Ahrnsbrak 1971) and by Modlin and Beeton (1970). The models constructed by these investigators were based on the following assumptions:

(i) that the Fox River is the sole source of excess salt (measured by the difference between electrical conductivities of river water, C_r, and Lake Michigan, C_m) supplied at constant flow rate and concentration;

(ii) that there is only one excess salt source (the Fox River) and only one sink (an "infinite" Lake Michigan);

(iii) that, within the gulf, the flux rates of both salt and water are conserved and the concentration field is stationary over the interval of the survey; and

(iv) that lakeward flux of excess salt is one-dimensional, i.e. concentration gradient s occur only along the gulf axis (taken as the x axis) and that lateral or vertical gradients are absent. (As we shall see, this assumption is often not supported by the facts).

Modlin and Beeton, making use of a simple estuarine mixing model (Ketchum, 1950) divided the Bay south of Gills Rock into four prisms or boxes, bounded on their northern sides by the cross-sections indicat ed by correspondingly numbered arrows in Figure 1.

The average "salt concentration" in each box was estimated from the results of detailed electrical conductivity surveys covering many stations (see later Figure 18); and the model was constructed as follows. The first box, south of cross-section No. 1 at Longtail Point, receives inflow from the Fox River (C_r assumed constant at 386 μ mho at $25^{\circ}C$) flowing at an assumed constant rate of $5.91 \times 10^6 \ m^3 \ day^{-1}$. Through the most northerly cross-section (No. 4) at Gills Rock, the fourth box receives water from the northern one-third of the Bay, assumed to be "Lake Michigan water" with C_m assumed constant at 258. Each fully-mixed box is assigned a constant conductivity, C_b, set equal to the observed average, and is in exchange with its neighbour(s) through the corresponding boundary cross-section(s).

Using Modlin and Beeton's data, I have assembled the four-box model in Figure 10. The river input to box 1 is 5.91×10^6 m^3 day^{-1} carrying an "excess salt concentration" expressed as excess conductivity units ($C_r - C_m = 386 - 258 = 128$). Each box is assigned an "observed" excess conductivity; $C_b - C_m$, shown as an italic "excess salt" number, ESN. Box volumes and the areas of inter-box cross-sections (broken lines) are also shown. The ESN's of boxes 1 and 2 are 82 and 21, respectively. To maintain those numbers at a steady state (and with the constant river input maintained at ESN 128) there has to be a northward flow, across cross-section 1, of ESN 82 (diluted river) water from box 1 into box 2 and a southward return flow of "entrainment" water (ESN 21) from box 2 to box 1. The conditions imposed by salt and water flux conservation can only be met at the flow rates indicated (non-italic numbers). Similar conservation arguments yield the steady-state rates of two-way exchange across the other inter-box interfaces in Figure 10 and between the last box and "Lake Michigan". As it continues northward, the river entrains more surrounding Bay water and becomes progressively diluted--a stepwise dilution from box to box in the model--accompanied by a corresponding southward flux of diluting water derived from the Lake. These results are assembled in Table 3. The volume transports across inter-box cross-sections also increase northward; but, because the cross-sectional areas also increase, the corresponding mean velocities show a much smaller range: 0.33 to 1.37 cm s^{-1}. It is of interest to note that the influx of "Lake Michigan" water into box 4($750 \; 10^6 \; m^3 \; d^{-1}$) corresponds to a speed of 1.67 cm s^{-1} averaged across the real gulf mouth (0.52 km^2), i.e. about one-third of the seiche current computed in Figure 6 and twenty-four times the mouth outflow corresponding to average total river input.

Modlin and Beeton computed "flushing rates" for each box (see Table 3; but for a reason yet to be explained these results do not agree with the 33, 127, 65, and 36 days values quoted by Modlin and Beeton, but no such discrepancy is seen when the same method is applied to Beeton, Smith and Hooper's 1967 comparable data for Saginaw Bay). However, accumulation or flushing of added materials in natural basins is an exponential process, and it is more realistic to make the model take account of this fact. For example, if the excess salt input at river (ESN 128) to box 1 in Figure 10 were suddenly reduced to zero without changing the water flow--and if the return flow from box 2 to box 1 were maintained unchanged at ESN 21--the ESN in box 1 would fall to one-half in 8 days, to one-quarter in 16 days, and so on.

Table 3. Volumes and percentages of Fox River water in the four boxes of the Figure 10 model, with corresponding flushing rates as defined by Modlin and Beeton (1970) and northward transport of diluted river water across inter-box cross-sections, based on August 1969 data.

	1	2	3	4
I. Box number and volume, km^3	0.11	3.82	4.06	26.84
II. Quantity of river water in each box:				
(a) by volume, km^3	0.07	0.63	0.35	0.21
(b) by % of box volume	64	16	8.6	0.8
(c) by % of total in all four boxes	6	50	28	17
III. Days of river flow required to supply II(a)*	12	106	59	35
IV. Interbox section area, km^2	0.12	.173	.264	.639
V. Northward transport:** Volume, 10^6 m^3 day^{-1}	10.37	69.15	75.06	755.5
Equivalent speed, m day^{-1}	864	400	284	1184
cm s^{-1}	1.00	0.46	0.33	1.37

* "Flushing rate" as defined by Modlin and Beeton (1970).

** Subtract river flow (5.91 10 m^3 day^{-1}) to obtain compensating southward transport of diluting lake water. Note: the entries in row III and V differ unimportantly from those published by Modlin and Beeton (1970).

Similar calculations for the remaining boxes--setting the salt influx in each case to zero but retaining the back-flux of salt from the next higher box--yields quartering times of 130 days for box 2, 42 days for box 3, and 44 days for box 4. In other words those are the times needed for the box ESN to move three-quarters of the way toward the new equilibrium.

With respect to pollution-abatement it should be noted that the rate of "flushing" response is most rapid in the river-dominated box 1 (ignoring possible release from sediments) and least rapid in box 2, which contains the greatest fraction of the total river water in the system. While more refined modelling, applied to Figure 10, would elucidate the combined response of all four boxes to changes in any part of the system, a rough calculation--taking the above-quoted three-quarter responses of single boxes and assuming a serial response--yields a total of 230 days for the three-quarters response of the four-box system, i.e. about the length of one year's open-water season and much less than the 6 years water renewal time calculated on the basis of gulf volume and water budget alone.

The model illustrated in Figure 10 is a box model with the salt flux and water flux conceptually separated; and, as we shall see later, there is evidence for some partial separation in reality. The second model which we shall consider (Ahrnsbrak and Ragotzkie 1970) is a gradient model, also flux-conserving, but treating concentration gradients and one-dimensional turbulent fluxes of salt and water across selected cross-sections (I to V in Fig. 1) in the along-gulf (the x) direction. The authors make the simplifying assumptions listed earlier and also make the not always justified assumption that no gradients exist and no fluxes occur in the cross-gulf or vertical directions. (See Figs. 16, 18a, and Ahrnsbrak's Fig. 14.)

Ahrnsbrak and Ragotzkie's basic equation, numerically solved, defines the time rate of change of excess salt concentration (C) at a given cross-section (of area A and normal to the x axis) as follows:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left(Q.C - K_x.A. \frac{\partial C}{\partial x} \right)$$

in which Q is the x-ward flux of river water through the section and $\partial C/\partial x$ is the salt concentration gradient along the x axis at the section. The equation distinguishes an advective term (Q.C) and a turbulent mixing term in which the "diffusivity" coefficient, K_x, is a measure of mixing intensity and includes contributions to across-section mixing by turbulent motions (and perhaps some more organized circulations also) occuring over a wide range (eddy spectrum) of space scales. The key feature of this model is the distinction between the action of advection and of turbulence in the lakeward transport of excess salt. The concept of turbulent mixing is more realistic and more amenable to further development than the physical separation of advective and entrainment flows visualized in Figure 10. The results however, in terms of mixing times and response to input changes, are similar in both models.

Ahrnsbrak and Ragotzkie compared the values of K_x, based on observed distributions of electrical conductivity (and, less successfully, water transparency), with values assigned to oscillatory seiche currents derived from the Heaps, Mortimer and Fee model described in the previous section. This comparison was prompted by the assumption that the seiche currents—which as we have seen are very active in the Bay--are the principal generators of turbulence. We later discuss other candidates for this role, but in any event Ahrnsbrak (1971) found an agreement between computed and observed estimates of K_x which was fairly close in spite of weaknesses in the data base. The following quotations summarize Ahrnsbrak's (1971) findings:

(i) "North of Long Tail Point the concentration of Fox River water decreases rapidly, a value of 25 percent seldom being exceeded 25 km from the mouth of the River. Lakeward, concentrations are very low and the effect of the Fox River is small."

(ii) "Diffusivities in the southernmost 15 km of the Bay are approximately 0.25×10^6 $cm^2.sec^{-1}$. Beyond this distance an abrupt increase to approximately 1.00×10^6 $cm^2.sec^{-1}$ occurs, followed by a gradual increase to approximately 3.00×10^6 $cm^2.sec^{-1}$ at 30 km. Lakeward the diffusivities decrease to approximately 0.7×10^6 $cm^2.sec^{-1}$ at 95 km." (Note that the distribution of seiche current speed in Fig. 6 is similar.)

(iii) "Diffusivity values of 0.2 to 0.3×10^6 $cm^2.sec^{-1}$ in the vicinity of Long Tail Point suggest a barrier to horizontal mixing in this area, while northward the larger diffusivities imply strong mixing and rapid transit of Fox River water."

(iv) "The time required for the central portion of the Bay to respond to changes in Fox River discharge rate is approximately 50 days, assuming a sinusoidal variation with a period of one year."

(v) "Assuming that the dispersive processes governing the summertime concentration field are in effect all year long*, the time required for the central portion of the Bay to respond to changes in pollutant concentration, without changing the discharge of the Fox River, is approximately 400 days." (Comparable to my earlier rough estimate of 230 days for the Fig. 10 model to register 3/4 of a step-like change.)

*reference is made later to Ahrnsbrak's observations of winter conditions under ice cover.

The two mixing models described above are one-dimensional with the limitations thereby implied. They describe an important component of the mixing process in the real gulf, but observations reviewed in the later section on currents will demonstrate that two-dimensional and probably three-dimensional processes are significantly at work.

Seasonal Cycles of Water Temperature

Each of the models considered in previous sections of this review are applicable to a homogeneous, i.e. unstratified gulf. During the open water season the shallow areas of the real gulf, including most of the Inner Bay, remain in fact unstratified or--only when the weather is calm enough--exhibit temporary stratification soon broken down by wind action. In the deeper regions of the gulf, north of Sturgeon Bay, stratification is expected to be more permanent from late spring to fall; although--it should be noted--there exist no systematic investigations of whole gulf temperature distribution, or of its seasonal development and decay, or of its responses to wind stresses acting upon the water surface. This is a serious deficiency in our knowledge of the hydrodynamics of the Bay and, to outline the probable picture, we must rely on speculation and on clues from sporadic biological and chemical surveys--most within the Inner Bay--and on what has been shown to happen elsewhere in the Great Lakes.

Except for the mouth region which is in communication with open water of Lake Michigan, most of the Bay is ice-covered in winter from late December to early April. There is variability from year to year, both in the extent of cover and in the dates of ice onset and break-up. Before the ice-cover is complete or has achieved its maximum extent, the open wind-exposed water will have been cooled down to temperatures (1^{o} or $2^{o}C$?) below that of maximum water density ($4^{o}C$). Under ice cover there will therefore be only a slight temperature (and density) stratification; any warmer inflows will form sinking plumes; and summer heat released from the sediments will--in appropriate topography--give rise to density currents as speculated in the next section. After ice break-up (late March or early April) the open water will initially be at sub-maximum density (at about $2^{o}C$?). Spring sunshine will then generate a strong positive flux of heat into the water over the whole of the gulf; but the rate of temperature rise will be most rapid in nearshore shallow regions. Under these conditions, a "thermal bar" convergence will form, with a nearshore strip of stratified water ($>4^{o}C$ at the surface) sharply separated from offshore unstratified water ($<4^{o}C$). As heating continues, the nearshore stratified strip will progressively widen; the thermal bar will migrate outward from the shores; and stratification will become eventually established over the whole surface. It remains to be seen whether the thermal bar is as strongly developed in Green Bay as in Lake Ontario (Rodgers 1966) where this process of stratification development lasts from mid-April until mid-June. The offshore cold water mass is deeper and more extensive in Ontario; and it therefore seems likely that thermal bars, if they form in the much shallower Bay, may be more vulnerable to wind disruption.

The paucity of temperature data for the Bay is illustrated by the fact that only two along-gulf transects are available (Ahrnsbrak 1971 for July 1969). They are illustrated—along with the "percentage" of Fox River water estimated from electrical conductivity in connection with the mixing model discussed in the previous section—in Figure 11; and they provide several clues. First (although not stated) the distribution of depth suggests that the cruise line started at Long Tail Point, followed the centerline of the Bay up to the 30 m contour, and then ran east of Green Island and west of Chambers Island, ending near Whaleback Shoal (see Fig. 1). Second, the conductivity gradient shows reversals not consistent with the model. Third, stratification is confined to water depth greater than 20 m; but a sharp thermocline was not present on the dates of the transect. Fourth, the different positions of the bottom ($<10^{\circ}C$) water on the bottom slope, and the disappearance of the $8^{\circ}C$ contour from the 30 July transect, suggest that extensive horizontal shifts occurred under the influence of wind or internal waves. Fifth, the large vertical excursions of the isotherm in the 60 to 100 km part of the 30 July transect suggest that large transverse slopes of the isotherms are sometimes to be expected.

This expectation is confirmed in Figure 12, which illustrates temperature distributions across two cross-sections at various dates covering the season of stratification. The larger cross-section (Ahrnsbrak's No. IV, see Fig. 1) is approximately 75 km from Long Tail Point and was traversed in August and September 1969. In the smaller cross-section (between 3 and II in Fig. 1, approximately 47 km from Long Tail Point) the isotherm distributions for June to September 1974 were derived from data in Patterson et al. (1975) obtained at the six most northerly stations of their survey. In that cross-section, on each of the four dates, the isotherms slope down toward the east. In Ahrnsbrak's Section IV an opposite slope is seen. The difference <u>may</u> reflect a difference in prevailing wind direction on the sampling dates or between the two years (1969, 1974) or it may provide evidence of dominant but differing circulation patterns in separate regions of the gulf. Obviously, more frequent and extensive surveys are needed to settle the matter.

The 1974 distributions are consistent with prevailing southerly or southwesterly winds. These, combined with the deflecting (Coriolis) force of Earth's rotation, would drag the surface warm layer to the eastward shore and transport it northward. If the observed isotherm slopes are in fact stable, there must be an accumulation of northward-flowing warm water on the eastward side of the gulf; but how stable those cross-gulf slopes are remains to be seen. My guess is that there will be episodic and sometimes dramatic changes, involving upwelling on the western (most frequently ?)

or eastern shores, produced respectively by north-directed and south-directed wind stress during storms. Although motion is expected to be most active in the upper layers directly affected by wind, the bottom layers will also move, often in directions opposed to the movement of the upper layer and often with internal to-and-fro "sloshing" forced by shifting winds or under the influence of internal waves. For example, the reappearance of cold bottom water ($9^{o}C$) in the August 1976 cross-section cannot have been the result of local cooling since the previous measurements in July, but must have resulted from advection of colder water from the north.

The stratified layers in the more northerly cross-section, IV, will also be subject to the effects just described; and the 1969 distributions may happen to coincide with east-shore upwelling after south-directed wind stress. However, that region of the gulf may also be subject to Lake Michigan influence, yet to be explored. For example, upwelling in the main Lake Michigan basin occurs not infrequently along the western shore, sometimes extending (as in Fig. 13) to the mouth of Green Bay, bringing much colder water to mouth level than exists in the Bay. That would set a gravity-driven exchange in motion with warm water flowing out of the Bay at the surface and cold water flowing inward at the bottom of the mouth channels and spreading into the deepest regions of the Bay. In this way, intermittent replenishment of bottom water may occur. On the other hand, when the Lake Michigan thermocline lies below the bottom of the mouth channels, an efflux of cold Bay bottom water will occur. Thus Lake Michigan exchanges with the Bay, not only mechanical energy in resonant seiching, but also heat and materials in water-mass transfers.

Current patterns, observed, modelled and postulated

In the preceeding section we learnt that little is known about the temperature structure of Green Bay or of its seasonal and shorter-term variability. Even less is known concerning the current structure. Saylor (1964) measured currents in Sturgeon Bay Canal, 12-14 Oct. 1963, and found them to be strongly correlated with semidiurnal "tidal" fluctuations in water level in Sturgeon Bay, which showed a range of about 12 cm. The corresponding currents in the canal (range $\pm$ 20 cm s^{-1}) transported a volume of 0.14 10^{6} m^{3} during each tidal cycle, i.e. about 5% of the daily Fox River flow in the Figure 10 model. But large wind-induced level differences between Bay and Lake could, Saylor noted, occasionally produce much higher speeds-- 2 m s^{-1} measured in one instance. During 1977 Dr. Saylor deployed recording current meters at several stations within the Bay and in the mouth channels. I hope that he will be able to give us a preliminary report on the results at the workshop.

Wind-driven and seiche-driven flows

In connection with an, as yet, unpublished attempt to verify the Heaps, Mortimer and Fee model mentioned earlier, I placed current meters and water level recorders during 1969 and 1970 in the mouth channels near Plum Island and St. Martins Island, with a level recorder also at Menominee, Michigan.

Records of current speed and direction in Death's Door (Porte des Morts) Passage, at mid-water depth (15 m) at the station marked with an asterisk near P in Figure 1, are assembled in Figure 14 with records of water level at Plum Island and Menominee (M in Fig. 1) and wind at Plum Island and Green Bay city airport. Only wind speeds of 10 knots or more were plotted, squared to provide a measure of stress on the water surface. Two spells of strong wind were observed. A steady blow from the north started during the evening of July 27 and ended during the morning of the 29th. A second storm, with winds varying in direction from S to WNW, lasted from the evening of the 30th to the morning of August 1st.

The northerly storm was preceeded and accompanied by strong pulses of east-going current, at the Death's Door recorder depth, reaching a maximum speed of over 40 cm s^{-1}. Accompanying oscillations in level appeared at Menominee and Plum Island (approximately in phase) and continued with a regular periodicity of about 12 h after the wind had stopped. During the calm interval (29 - 30 July) rising and falling Bay levels were, respectively, closely correlated with westward (ingoing) and eastward (outgoing) currents in the Passage; and pulses in current speed were correlated, although less regularly, with maxima in the rates of level rise and fall. At the times of change-over in current direction, current speeds fell to low values.

The relative regularity of the oscillation in water levels and current direction was then interrupted by the second storm; the current direction turned westward and held relatively steadily in that direction (i.e. against the wind) showing three large pulses in speed. At the end of the storm on 1 August, the current speed fell; the direction fluctuated erratically; and the steady 12 h oscillation in water level re-appeared. There was a strong westward current pulse during the morning of 2nd August, in the absence of wind; and slower westward currents persisted for the next two days.

In addition to the inward and outward currents pulsating in phase with the oscillation in Bay water level, the principal results seen in Figure 14 are pulses of strong outward (east-going) current, at the depth of the instrument, during a northerly wind stress and inward (west-going) current during south to westerly winds. (There was also an oscillation of water temperature at the instrument, approximately in phase with level change at Plum Island, but difficult to interpret without knowledge of the temperature structure and changes in thermocline depth in the vicinity.) The mechanics of the responses to wind stress in other regions of the Bay and in various channels of the mouth can be explored with appropriate models, for which records of the type presented in Figure 14 can provide tests. This work is in its early stages, but preliminary predictions of the Heaps, Mortimer and Fee model are of interest here. The model, as mentioned earlier, investigates the effects of wind stress and mouth-level changes on water surface elevations and currents in an unstratified Bay coupled with the northern half of Lake Michigan; and the earlier Figure 7 illustrates the elevation changes produced after 40 h of steady wind blowing along the Bay axis toward the head (8 m s^{-1} from 38^{o} E of N, with no wind over the Lake). The picture of current distribution corresponding to Figure 7 is presented in Figure 15, i.e. at 40 h after wind onset. At the point corresponding to Figure 14 the model shows an outgoing (eastward) current, which had persisted (although with fluctuating velocity) for the previous 34 h, i.e. starting 6 h after wind onset. Similar results were obtained when the model was run with steady northerly wind over Bay and Lake. These model results are in agreement with the observed eastward current in Death's Door Passage during a real northerly wind (Fig. 14). But the model (Fig. 15) shows a great deal more. For example, while water is flowing out of Death's Door, a westward current flowing into the Bay through the most northerly channels of the mouth contributes to the gyre circulation seen in the widest section of the Bay. (No model runs with westerly wind are, as yet, available to compare with the ingoing current at Death's Door seen in Figure 14 during the second storm.)

Other organized flow patterns are seen in Figure 15. In the Inner Bay, the currents in the shallow nearshore regions on both sides are driven with the wind, producing (as Figure 7 shows) a pile-up of water toward the head of the Bay (11 cm above equilibrium at the head). The pressure gradient, associated with that set-up, drives a countercurrent against the wind along the deeper center axis of the gulf where friction is less than at the sides. There is evidence of counterclockwise circulation around Chambers Island. There is also a strong counterclockwise circulation around Big Bay de Noc, but no motion in Little Bay de Noc. The regions of greatest horizontal shear, in the northerly wind case and expected to correspond to a region of high horizontal turbulence, is encountered along the eastern shore of the Inner Bay and NW of Chambers Island. There a strong coastal current runs southward along the shore, while a strong northward current is seen in the next compartment row. The series of model pictures leading up to Figure 15 confirm the presence of similar "steady" current patterns, but also demonstrate rythmic changes in speed and direction, i.e. seiche currents corresponding to the elevation oscillations displayed in Figure 8.

Water-mass labelled flows

One limitation of "storm surge" models of the type just described is that, with their assumption of a homogeneous water column, they cannot reproduce stratified flows. There is evidence that these are also important in the Bay. Our earlier examination of mixing models demonstrated how the excess-salt label of the Fox River may be used to provide estimates of one-dimensional mixing and transport. The same label can also be used to shed light on two-(and three-) dimensional flow patterns near the head of the Bay. In Modlin and Beeton's picture for July 1968 (Fig. 16--a year of relatively high river flow) a tongue of diluted river water can be traced for 25 miles (40 km) from the river mouth along the eastern shore. Except for an unusually large July flood (Fig. 17), the next year was a year of generally lower summer inflow (Modlin and Beeton 1970) and, although similar tongues of mixed river water were again seen close to the eastern shore (Fig. 18) they were much less extensive than in the 1968 example; and they decreased in length during the five weeks covered by the figure. That decrease can be attributed to dissipation of the July flood influx, after which the river flow rate fell to low values (Fig. 17).

The apparently persistent pattern illustrated in Figures 16 and 18--a rightward deflection of the river water entering the Bay--is seen in other lakes in which river inflow is both large and distinctive. In the Green Bay example, the pattern can be attributed to the combined influence of prevailing S-SW winds and the rightward deflecting force of Earth's rotation--the Coriolis force. During northerly storms, the pattern may be disrupted or destroyed (Ahrnsbrak and Ragotzkie 1970) as may be inferred from the model in Figure 15. Other authors, noting this pattern, have postulated a compensatory southward current along the western shoreline carrying water which has been diluted by water from Lake Michigan entering at the mouth. In fact, E-W gradients of water properties are sometimes seen, consistent with this concept--for example, the conductivity contours in Figures 16 and 18 (a) and the striking E-W difference in water clarity (Fig. 19) demonstrated by "F.J. Bates" in Howmiller and Beeton (1971-in fact F.W.N. Bates). But direct measurements of this postulated southward counter-current have yet to be made. No evidence of it was found in an extensive drift-bottle experiment, the results of which are reported by Howmiller and Beeton (1971) and illustrated in Figure 19. Seven bottles were released at each station. All the recovered drift bottles had moved northeastward, but none were returned from Station 11 and only one from Station 15, the two most westerly stations. A southward drift, if it occured at those stations, would have carried the bottles to regions of the shore where recovery was unlikely. In any event, drift bottles respond only to surface wind drift and to direct wind action on the emergent part of the bottle. Subsurface counter-currents are not recorded by this method.

Drift bottles and dye were also used to explore local circulations in Little Bay de Noc (Ryckman 1968); and various water-mass labels (ions, color) served to disclose summer and winter current patterns in that Bay (Mayhew 1972).

Flow under winter ice-cover

During winter, when the Bay is largely protected from wind action by ice cover, a rightward-deflected Fox River tongue also develops, rendered visible (Fig. 20) by low oxygen concentration and high electrical conductivity, expressed here as percent river water. The cross-sectional distributions of conductivity (Fig. 20d, Ahrnsbrak, 1971) display a plume which has not only sunk, but has also been deflected to the right. The deflection and the sinking can plausibly and respectively be attributed to the deflecting (Coriolis) force arising from Earth's rotation and to a density difference between river and Bay water. River flow continues at a low level during the winter (Fig. 17); and if the Bay (at about 1°C or less, see Fig. 20c) receives river water at a higher, even slightly higher temperature, the river plume will sink. In that case one would expect the temperature and conductivity fields to appear similar. However, except at Section D (Fig. 20) , that was not the case in February 1970.

A comparison between the oxygen and conductivity distributions, in Figure 20 (a) and (b), is instructive even though they are from different years. The plumes in each case are of similar length and extent, but conductivity decreases away from the river mouth, whereas oxygen deficit does not. The minimum concentration (3.7 mg L^{-1} O_2) lies near the northern tip of the plume, while more than double that concentration is found near the river mouth. This suggests that an oxygen-demanding plume entered in early winter, later followed by water of higher oxygen content and/or with lower oxygen demand. The highest concentration, 12.6 mg L^{-1} O_2 found in the western half of the inner bay, corresponds to 86% saturation at 1°C (Wetzel 1975, p. 666). In that water, little oxygen was lost during the season of ice-cover, assuming no active advection from ice-free regions. On the other hand, the minimum concentration (3.7 mg L^{-1}) corresponds to 26% saturation at 1°C. Oxygen content, unlike conductivity, is not a conservative tracer; and this is well illustrated in Figure 20(a) by the difference between the March and May distributions, i.e. with and without ice cover. The river plume was probably still in place in May--note its conductivity-labelled persistence in Fig. 18--but wind-stirring and re-aeration of the Bay after ice-out confined the low-oxygen region to a small area just off the river mouth.

Before we leave the winter scene, other possible currents under ice should be considered. Apart from evidence of a sinking river plume just described, winter currents can as yet only be the subject of speculation. With the major stirring force--the wind--removed by ice cover, circulation is very different from that in summer. It is probable that density currents will assume an important role. Too slow to measure directly, these currents will have to be inferred from under-ice redistributions of water masses, distinguished by their temperature and/or chemical characteristics. Earlier work on lakes in Swedish Lapland (Mortimer and Mackereth 1958) demonstrated that in large, wind-exposed basins the whole water mass cools to temperatures below 4°C (the temperature of maximum density) before ice forms on the surface during calm, cold nights. After ice has formed, the sediments (containing stored summer heat) warm a thin layer of contact water which therefore increases slightly in density. On the sloping sides of the basin, that slightly denser contact water flows down the slope as a density current and accumulates in the nearest depression or "sump". Similar conditions, anticipated in Green Bay, may cause "sump-filling" if the depressions noted at G,D, and W in Figure 1 are extensive enough. The contact water exchanges not only heat, but also solutes (oxygen and bicarbonate ions, for example) with the sediment, producing not only a temperature stratification, but also a chemical stratification in the depression. If the basin has more than one depression, as was the case in the Swedish lakes, the separated depressions differ in their final temperature and chemical profiles, depending on the extent and chemical properties of the sediment in the respective "drainage areas".

Contrary to Ahrnsbrak's (1971) supposition, seiche currents are not absent in winter, because--although direct wind action on the Bay water surface is prevented--changes in atmospheric pressure act on the ice sheet, water level changes induced by Lake Michigan motions still occur at the mouth, and the tide-generating forces are always present. Therefore resonant seiches and tides occur in winter with not much diminished amplitude, as shown by the 1963 spectrum in Figure 9, obtained from records made during two months' ice cover. To these long-wave motions, the ice sheet appears to respond elastically.

Currents during the season of stratification, June to October

Circulation patterns in the main part of the gulf, when it is stratified, can only be speculated upon in the light of Figure 12 and what is known of responses over a wide range of time scales in large stratified lakes. The mean pattern for the whole season is likely to be a counterclockwise gyre, for reasons adduced by Csanady (1977), flowing at an anticipated speed of not more than one or two centimeters per second. But, over time scales of days, considerably higher speeds will occasionally be encountered. Episodic wind-driven currents will be strongly coupled to storm passages, as will also displacements of the stratified water masses leading to upwelling/downwelling motions near shore and to internal seiching (see-saw swinging) of the thermocline. Also, storms on Lake Michigan will produce considerable variation in the water-mass structure at the mouth of the gulf, thereby influencing the pressure gradients which control flow into or out of the Bay at the surface, at the bottom, or at intermediate levels.

In so short of a review, it is impossible to present descriptive accounts or models of the various types of motion expected in a large shallow gulf. Some of these characteristic "large-lake" motions are reviewed, with Great Lakes examples, in Mortimer (1974). They may be listed as follows, with the characteristics of the associated currents listed in brackets:

(a) Wind-driven surface drift (running with or up to 40° to the right of the wind, most rapidly at the surface and constrained to flow shore-parallel when meeting a coastline);

(b) Gradient currents, produced by pressure gradients associated with wind-induced tilt ("set-up") of the water surface or thermocline (often running below and counter to the surface wind drift);

(c) Upwelling of the thermocline (because of the Coriolis effect, upwelling is usually seen along coastlines lying to the left looking downwind; often accompanied by downwelling along the opposite shore; associated with shore-parallel currents in approximate "geostrophic" equilibrium, i.e. with the Coriolis force balanced by the pressure gradient produced by the thermocline tilt);

(d) Internal Kelvin wave response to extensive perturbations of thermocline level (upwelling/downwelling, for example) and set in motion after the original storm stress has passed (characterized by shore-parallel currents, most rapid near shore, decreasing logarithmically in the offshore direction, and falling to negligible speeds at 10 km offshore, i.e. negligible in the middle of the main gulf);

(e) Cross-gulf seiche motions of the thermocline (internal Poincaré wave response to extensive perturbations in thermocline level) with a periodicity slightly less than the local inertial period of 18 h in Green Bay (characterized by current directions which rotate clockwise with the same near-inertial periodicity i.e. a circular motion difficult to distinguish from "true" inertial motion of a mass moving at constant speed with no forces except Coriolis acting upon it);

(f) Surface seiches described in a previous section with the first gulf seiche mode dominant and with currents oscillating to-and-fro, generally along the main axis of the gulf and with a period of about 11 h, with an anticipated maximum speed near Chambers Island);

(g) Gradient currents associated with water-mass distribution near the mouth and with Lake/Bay density differences (seen mainly as inward- and outward-going currents in the mouth, sometimes running concurrently in different directions at different levels or through different channels, but also affecting the open Bay particularly the deeper regions).

In addition to river-induced flows (negligible in the outer Bay) and the whole-gulf gyres of the mean circulation, each of the seven above-listed current types will probably be found at various times in different combinations and proportions depending on incidence, characteristics, and timing of storms. All of these components will contribute to the spectrum of smaller-scale turbulent motions which drive the mixing processes. To this complexity must also be added the wakes and eddies produced by islands and shoreline prominences which lie in the path of currents (Barkley 1973).

Several of the above-listed current mechanisms contribute to shore-parallel flow patterns. For example, upwelling and downwelling motions are strongest a few kilometers from shore; and internal Kelvin waves exert their maximum effect within 5 km of shore. It is in that zone, therefore, that most of the gulf's kinetic energy will be found and where shore-parallel motion will be dominant. In mid-gulf on the other hand, rotating "inertial" currents are to be expected--of 17-18 h period and set in motion by wind impulses and by internal seiching of the thermocline (Mortimer 1977)—often in combination with the 11 h oscillating surface seiche currents and with more or less steady currents. What such combinations would look like, in terms of the current tracks they produce, is illustrated for three simple cases in Figure 21. Each combination is made up of two components: a rotating inertial component of speed 1.0 and a surface seiche component of maximum speed $\pm$ 0.5. To these components is added a undirectional current component of speed 0.25 in case (a), 0.5 in case (b) and 1.0 in case (c), i.e. only the speed of the unidirectional component is varied. The inertial period is taken as 18 h, the seiche period as 12 h, and vectors at 2 h intervals are drawn (inset, top-left in Fig. 21) for the inertial, the seiche, and the unidirectional current. Those three vector components are combined, and the resultant "current tracks" are plotted as progressive vector diagrams. The results, in Figure 21, suggest that looping, cusping, and meandering current tracks are to be expected in the real gulf, depending on the relative contributions of the components. Confirmation that similar current patterns occur in nature is to be found in Sato and Mortimer's (1975) report on coastal currents in Lake Michigan, which gives a probably reliable preview of current patterns—and their wind-dependence—yet to be unravelled in Green Bay.

Promising Research Strategies

Future research strategies will depend on which questions are deemed most fundamental or urgent and on what means are available to answer them. As questions and strategies are to be explored at the workshop, it will be more profitable to write this section afterwards, with the advantage of insights which the group will provide. In the meantime, some brief suggestions arising from the foregoing review may stimulate our discussions.

The general objective of the hydrodynamicist is, and will remain, development of ability to understand and predict the responses of the water masses of the Bay to the forces acting upon them, to the seasonal cycle of heat flux, and to interactions with Lake Michigan and inflowing rivers. The immediate objective is to improve that understanding and predictive ability to a point where it can provide useful advances in parallel understanding and prediction of chemical and biological events and processes. A primary need in this connection is a more complete description of circulation patterns, mixing processes, and the field of turbulence. Because, as the foregoing review demonstrates, those patterns and processes are more guessed at than known, a more systematic exploration of the real Bay is required; better mixing models must be constructed and verified by repeated surveys of water-mass labels, taking the variability of inflow (see Fig. 17) from the Fox and other main rivers into account; and more effort must be devoted to development and field verification of circulation models applicable to stratified as well as unstratified conditions.

Fortunately the Bay is small enough for an orchestrated effort with one or two small research vessels—a "Green Bay Expedition"—working systematically through one or two seasons, to add much to the little that is now known, particularly concerning the history and dynamics of stratification and associated internal motions. Among these, the properties of shearing flow in stratified fluids have particular significance in controlling the growth and decay of turbulence and in regulating mixing and nutrient exchange across the thermocline, i.e. processes of prime biological significance. In fact it can be argued that, for the chemists and biologists the vertical and horizontal shears associated with spatial variability in currents are more important than the currents themselves. But our present measuring instruments and measuring programs are poorly designed to investigate these shears. For while it has long been easy, for example, to measure the vertical (and horizontal) distribution of temperature, measurement of the vertical (and horizontal) distribution of flow is only now becoming possible with the degree of resolution required to predict the growth and decay of turbulence in vertical shears and the structure of the eddy spectrum of horizontal turbulence.

In attempting to design a meaningful experimental program for Green Bay, strategies successful elsewhere should prove rewarding--for example, repeated scanning of cross-sectional distributions of temperature and other physical variables (conductivity, transparency) using "continuous" profiling and recording techniques, in order to increase the spatial and temporal resolution. It would be further rewarding to combine such physical surveys with sampling of important chemical and biological variables (for example, oxygen, nutrients, chlorophyll) again using profiling techniques and on-board recording or analysis where possible. Much would also be learnt from repeated synoptic pictures of surface temperature and other optical properties, using airborne equipment. A new generation of *in situ* recording instruments is needed to provide repeated vertical profiles of temperature (density), flow and other variables of interest. And--in combination with such fixed-station (Eulerian) measurements--free-floating current followers (Lagrangian devices) should be developed and deployed to define the current tracks and horizontal eddy structure. Finally, much can be learnt about physical and biological processes in the Bay, and their history, by appropriate studies of the sedimentary record.

Involving, as it does, instrument development and data-gathering on a large scale--a well-founded Green Bay Expedition in fact--the program here outlined would rightly encounter criticism if it were yet another data-gathering effort. To be effective and to receive the support it will need, the Expedition must be expressly designed to answer critical questions, supply key information, and to test a developing generation of predictive models. For it must be continually emphasized--to researchers and managers alike--that the predictive power, which environmental managers demand of hydrodynamic and ecosystem models, can only be produced and effectively applied when, and only when, those models have been tested and rooted in the real world. Modellers can create many scenarios; nature has only one, and that is the one which we must strive to understand. Wordsworth, the Lake Country poet, put it well: "To the solid ground of nature trusts the mind that builds for aye".

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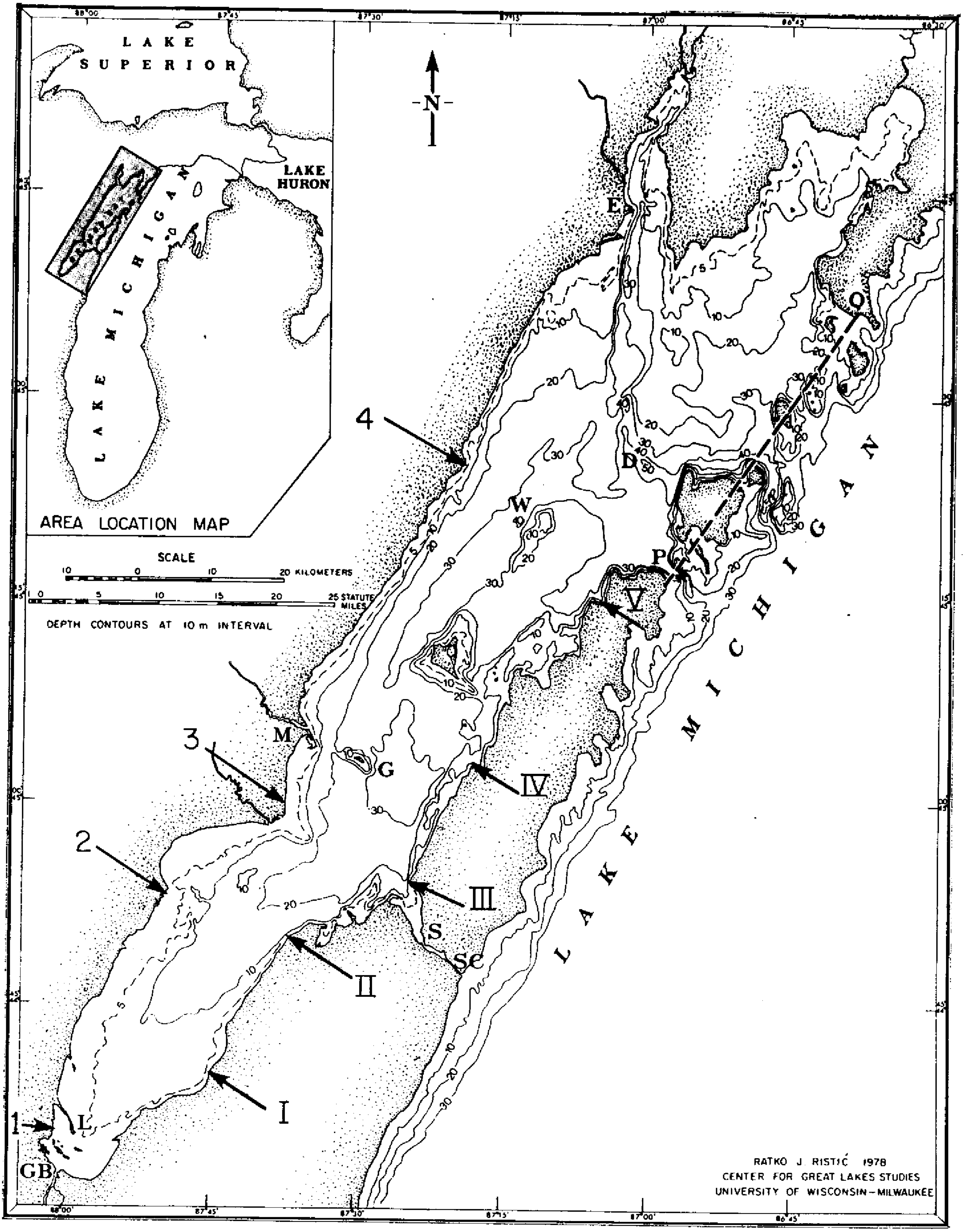


Fig. 1: Chart of the Green Bay arm of Lake Michigan. GB, M, E indicate the positions of the following towns: Green Bay, WI; Menominee, MI; Escanaba, MI; P denotes Plum Island; and the line PQ is taken as the mouth of the gulf. Other letters, numbers and symbols are referred to in the text.

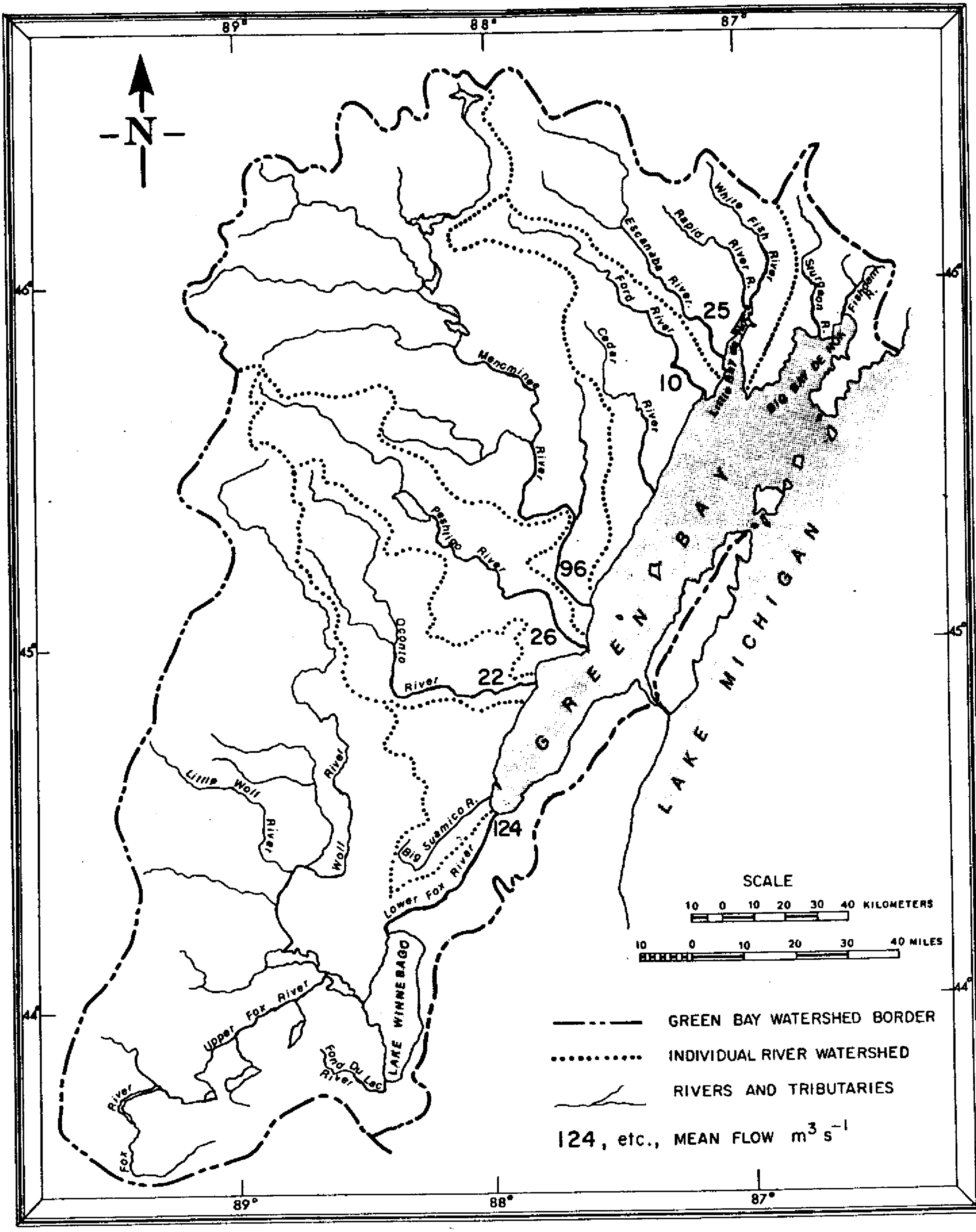


Fig. 2: The Green Bay watershed with mean flow rates ($m^3\ s^{-1}$) indicated for the principal tributaries (see Table 2). (Seasonal variation in Fox River flow is illustrated in Fig. 17.)

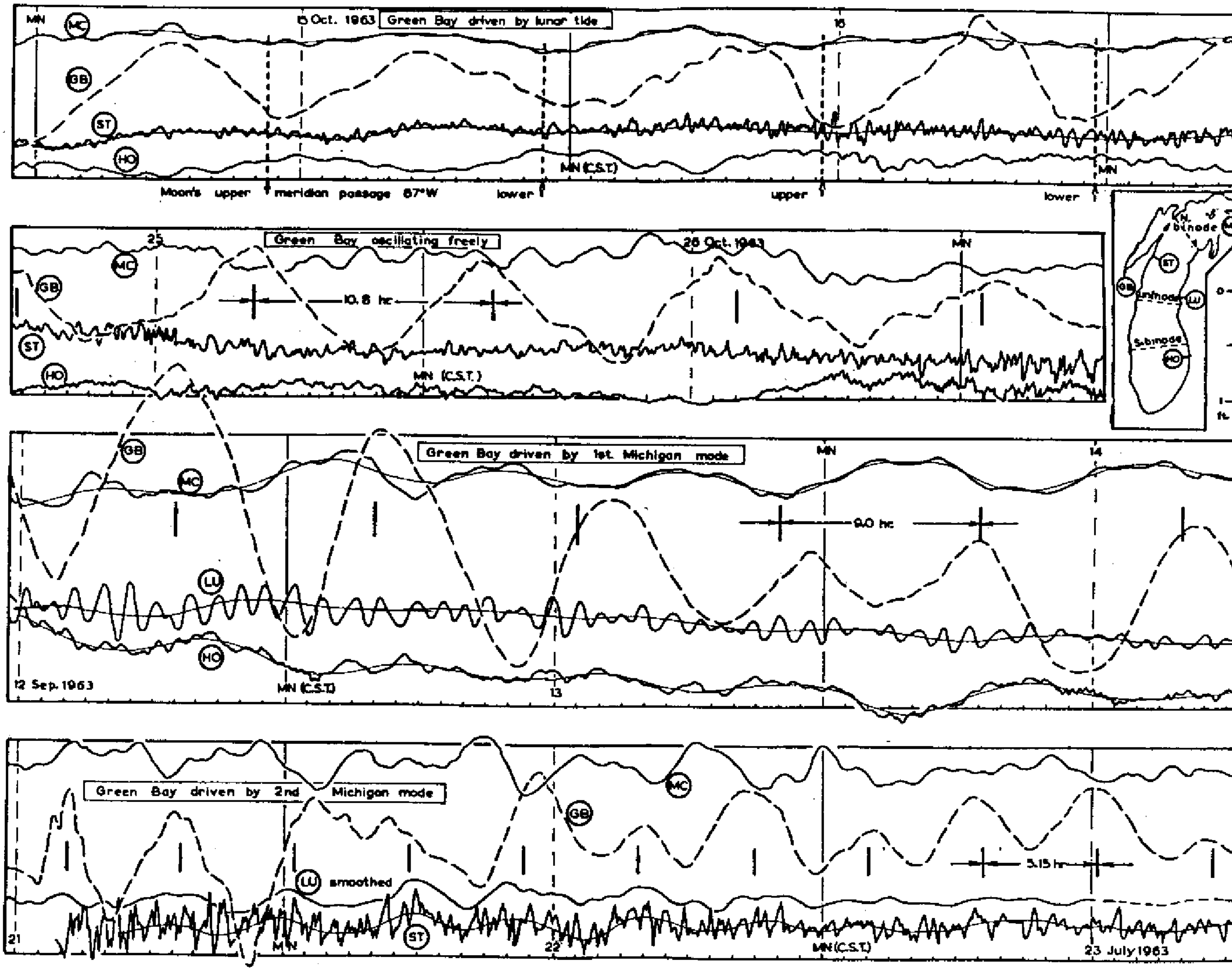


Fig. 3: Four episodes of water level fluctuations at Lake Michigan shore stations (MC Mackinaw City, ST Sturgeon Bay Canal, LU Ludington, HO Holland—positions shown in inset map) and at Green Bay city (GB, broken line). This figure, reproduced unchanged from Mortimer (1965), was accompanied by the following interpretation, modified somewhat in the light of recent work described in this review: "The second episode, 25–27 October 1963, illustrates the free oscillation of the Bay uninfluenced by the Lake; while the other three episodes (15–17 October, 12–14 September, and 21–23 July, 1963) illustrate conditions in which the Bay oscillation was driven, respectively, by the semidiurnal tide and the 1st and 2nd longitudinal Lake modes."

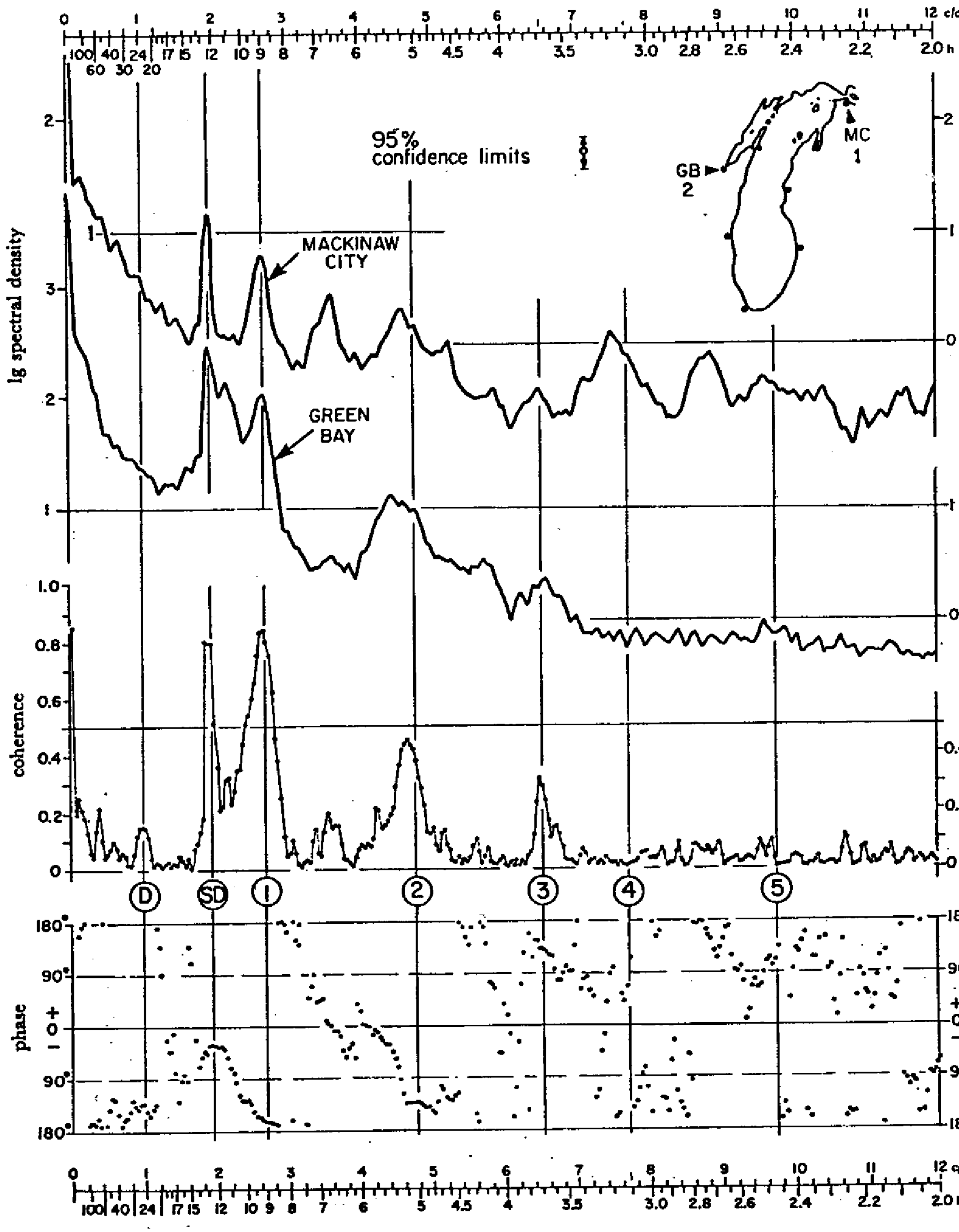


Fig. 4: Lake Michigan: power spectra of water level fluctuations at Mackinaw City (MC) and Green Bay city (GB) and spectra of coherence and phase difference between those stations. Peaks labelled D, SD and 1 to 5 correspond to the diurnal and semidiurnal tides and to the first five seiche modes, respectively. (from Mortimer and Fee 1976).

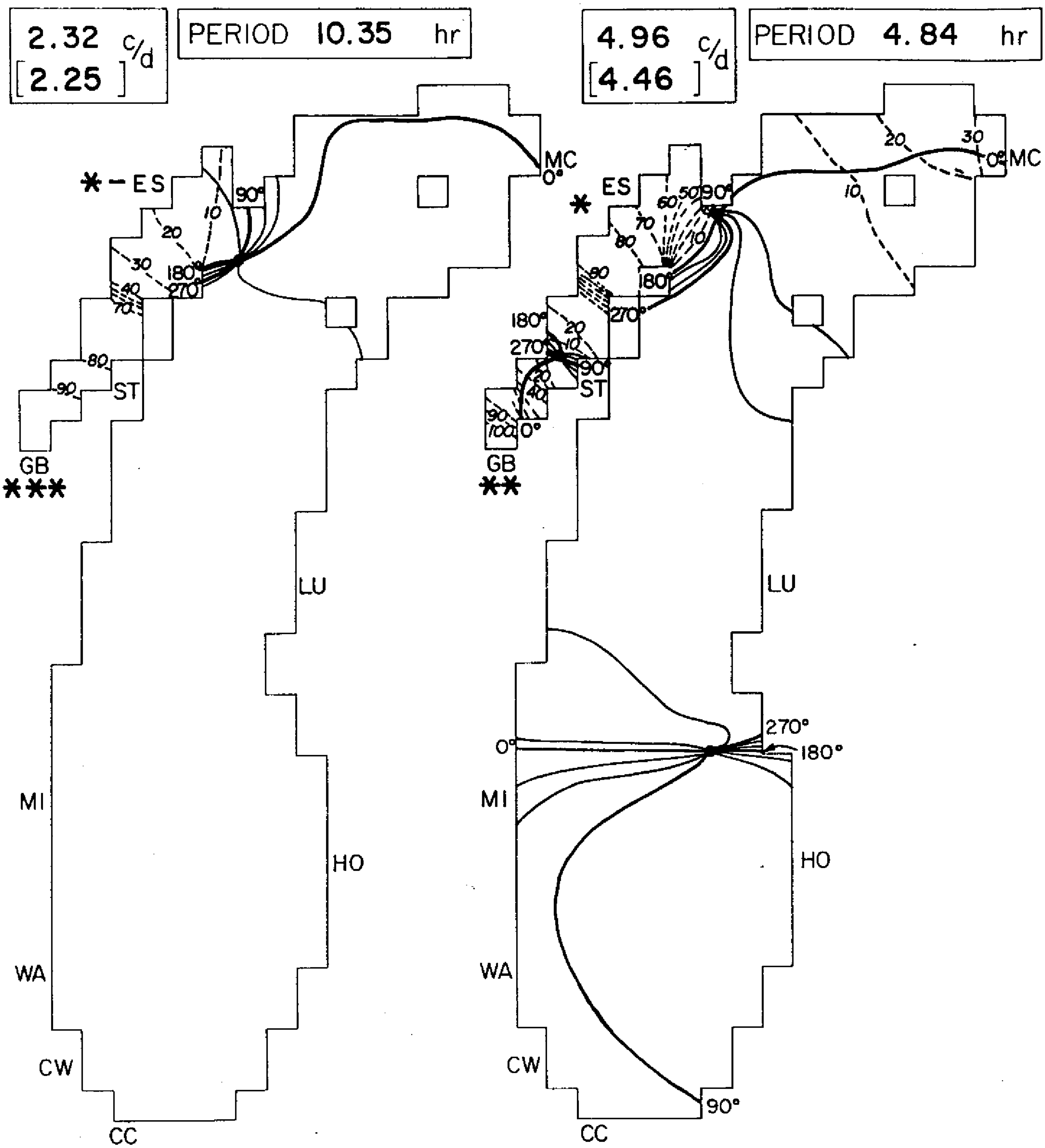


Fig. 5: Calculated frequency, period and structure of the first two modes of Green Bay co-oscillating with the main Lake Michigan basin, taking the earth's rotation into account. Phase progression relative to 0° at MC, is shown by co-tidal lines (heavy for 0°, 90°, 180° and 270°, light for 30° intervals). Distribution of relative elevation range is shown by co-range lines, broken and relative to 100 at that grid point which exhibits maximum range for the mode concerned. The bracketed "observed" frequency at the head of the figure is that of the particular spectral peak identified with the calculated mode. Asterisks characterize the magnitude of spectral peaks observed for that frequency at the station indicated: ***very large; ** large; *present; *-present but small. (From Rao, Mortimer, and Schwab, 1976). Note that, except for mode 2 at MC, these "Bay" modes show less than 10% amplitude in the main Lake basin.

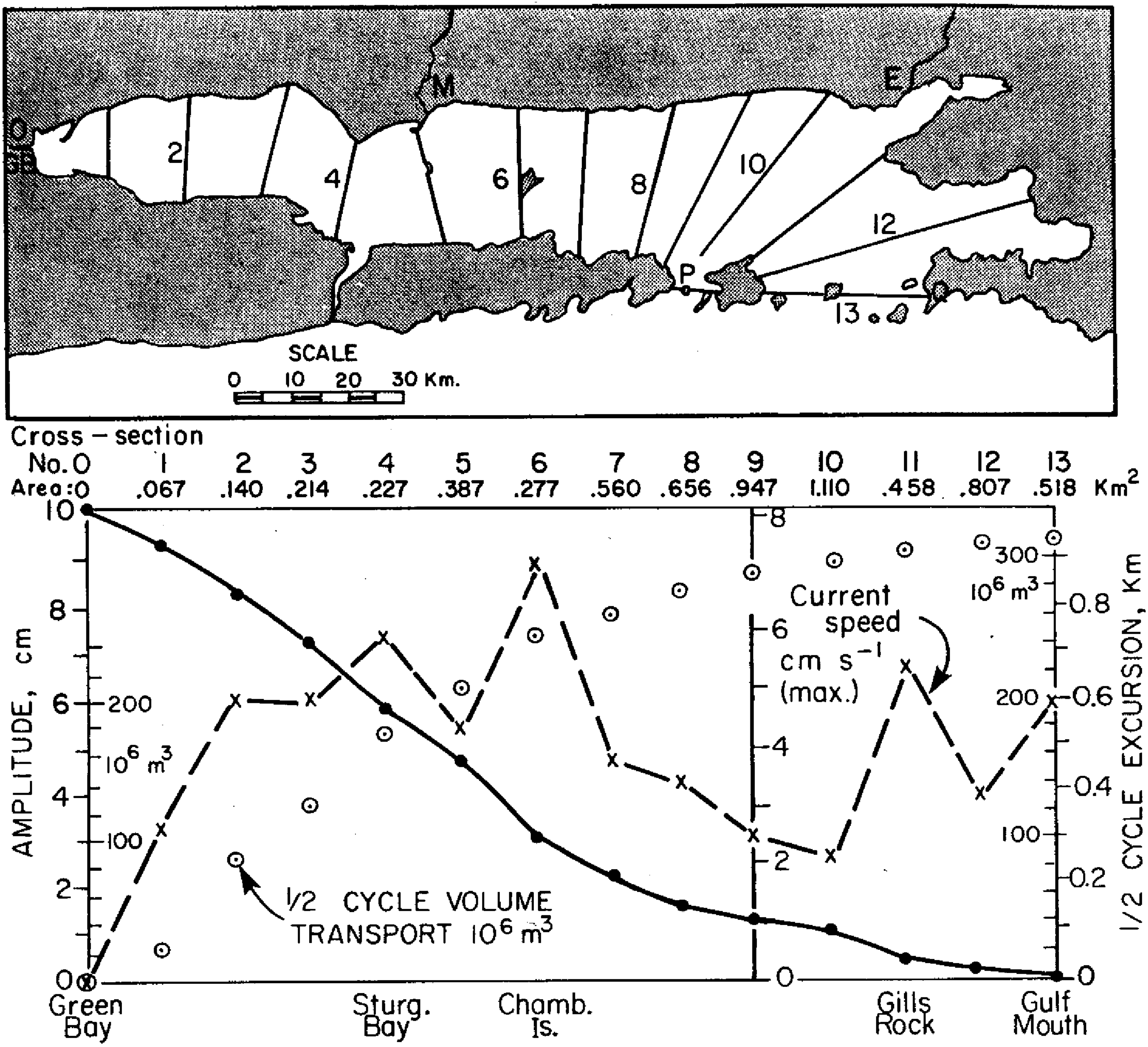


Fig. 6: One-dimensional (Defant 1918) model of Green Bay, oscillating as a gulf in the first mode with: a period computed at 10.8 h; a nodal line at Section 13; and a seiche amplitude of 10 cm at Section O. Illustrated are: along-gulf distribution of amplitude (dots); total transport through each section during half the seiche cycle (open circles); and corresponding half-cycle water-mass excursions and maximum current speed at each section (crosses). The half-cycle mean current speed is $2/\pi$ times the maximum. (Map and data from Mortimer 1965.)

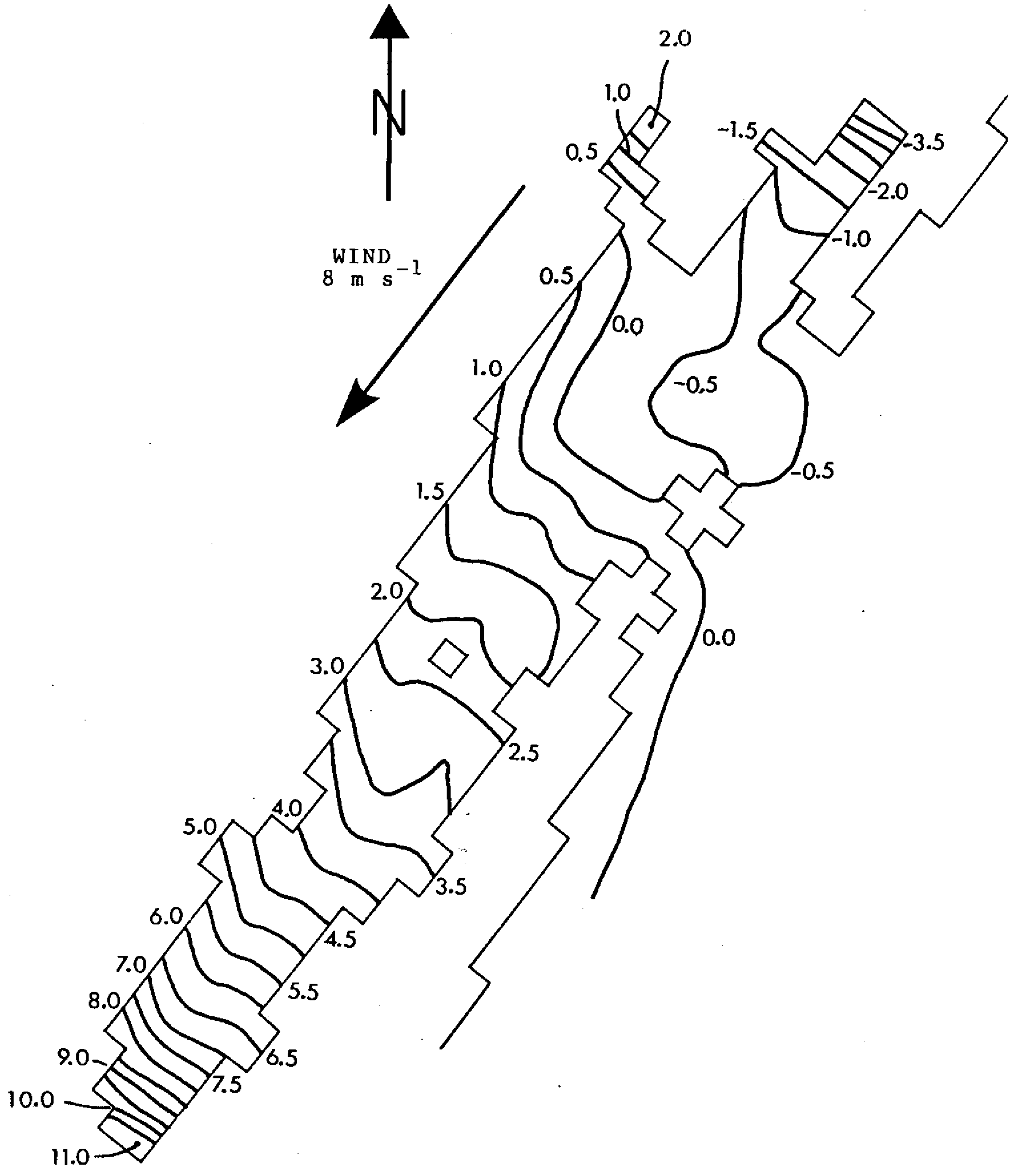


Fig. 7: Green Bay and northern Lake Michigan (not shown): distribution of surface elevation (cm above equilibrium) predicted by a model described in the text (Heaps, Mortimer, and Fee, unpublished) after a steady wind (uniformly distributed over the Bay, with no wind over the main Lake) has been blowing at 8 m s^{-1} from N 38° for 40 hours. The corresponding distribution of current is illustrated in Fig. 15.

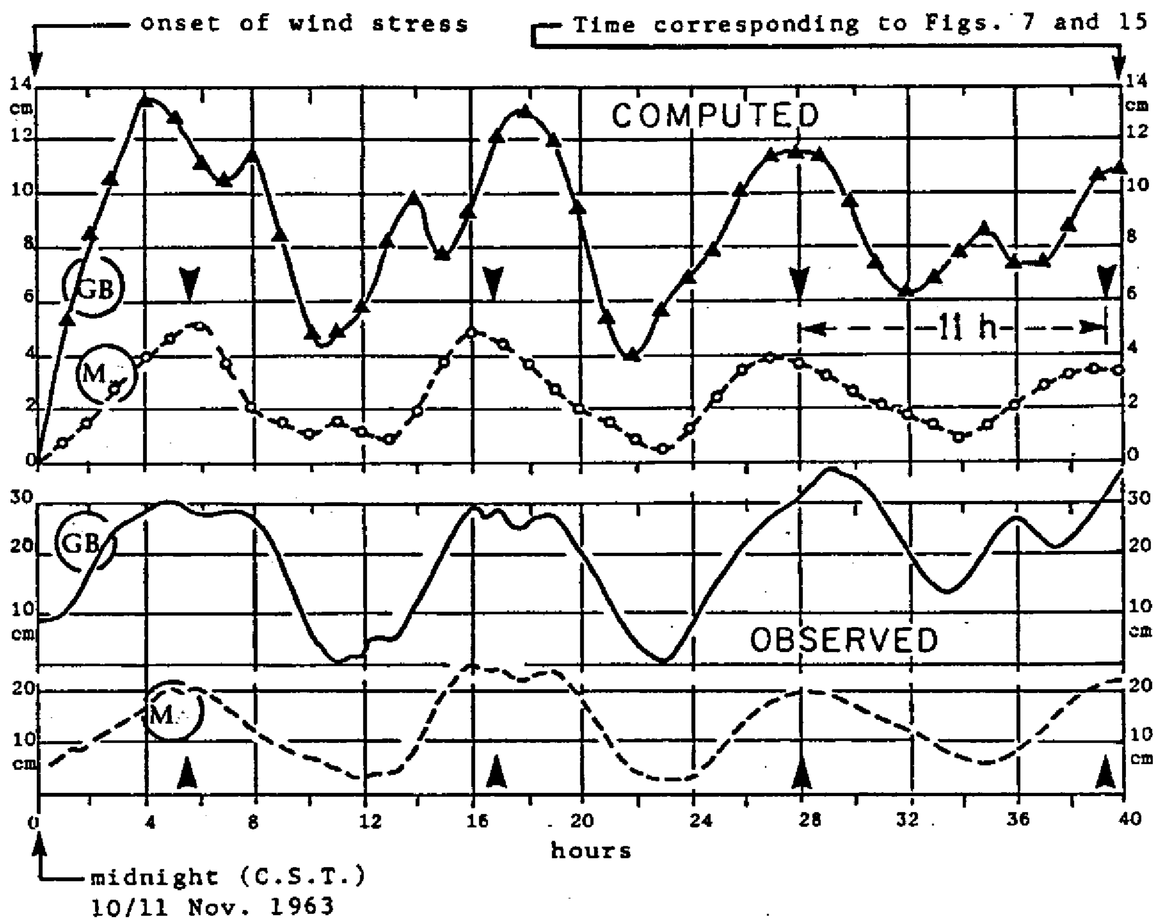


Fig. 8: Comparison of computed and observed water levels at Green Bay city (GB) and Menominee (M). The computed levels display the response—to a steady wind (8 m s^{-1}) from 38° E of N, blowing over the Bay but not over the Lake for 40 h—at grid points corresponding to GB and M in the model referred to in the text (and Fig. 7). Arrowheads are placed at 11 h intervals

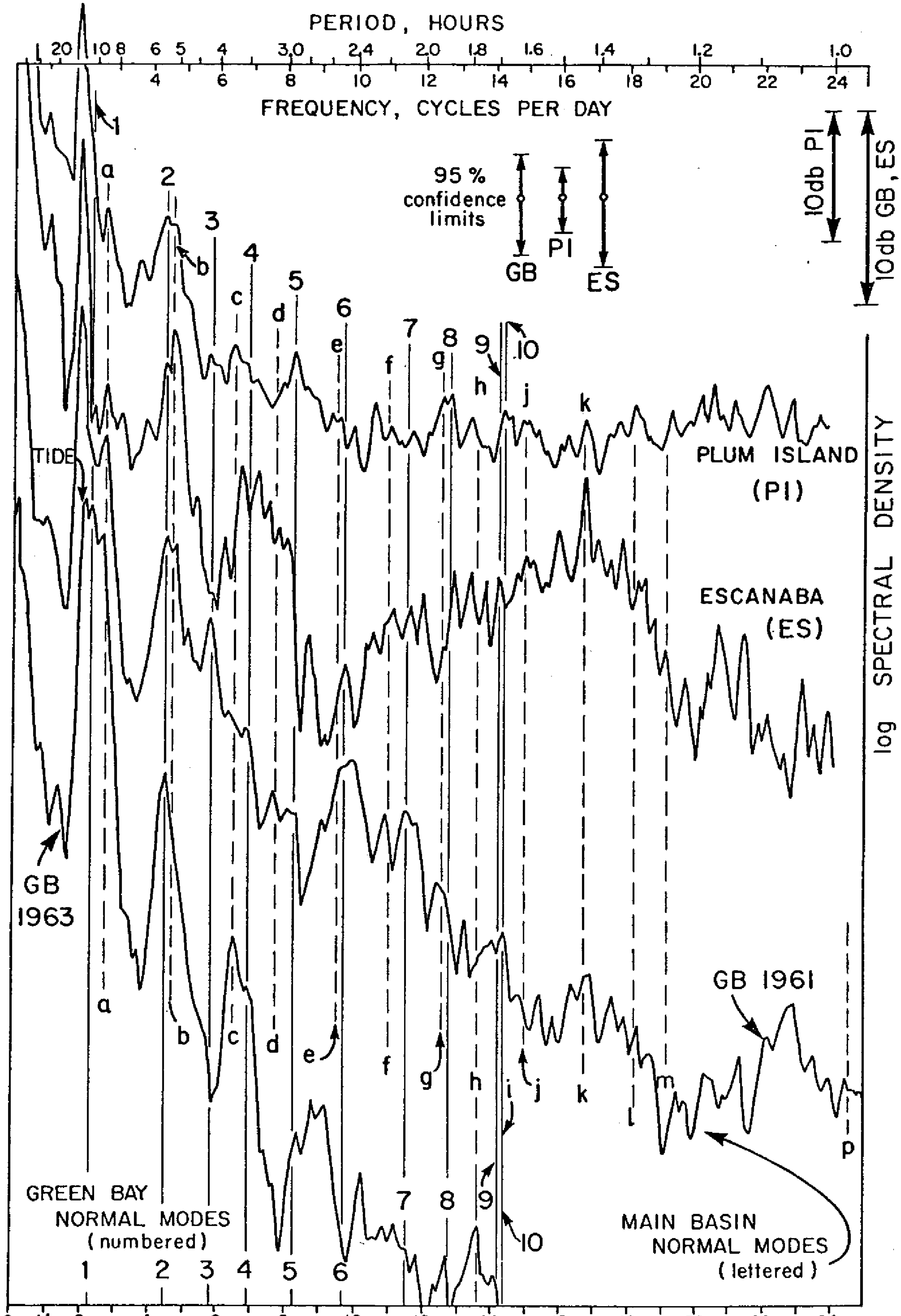


Fig. 9: The legend is placed under that of Fig. 10 (next page).

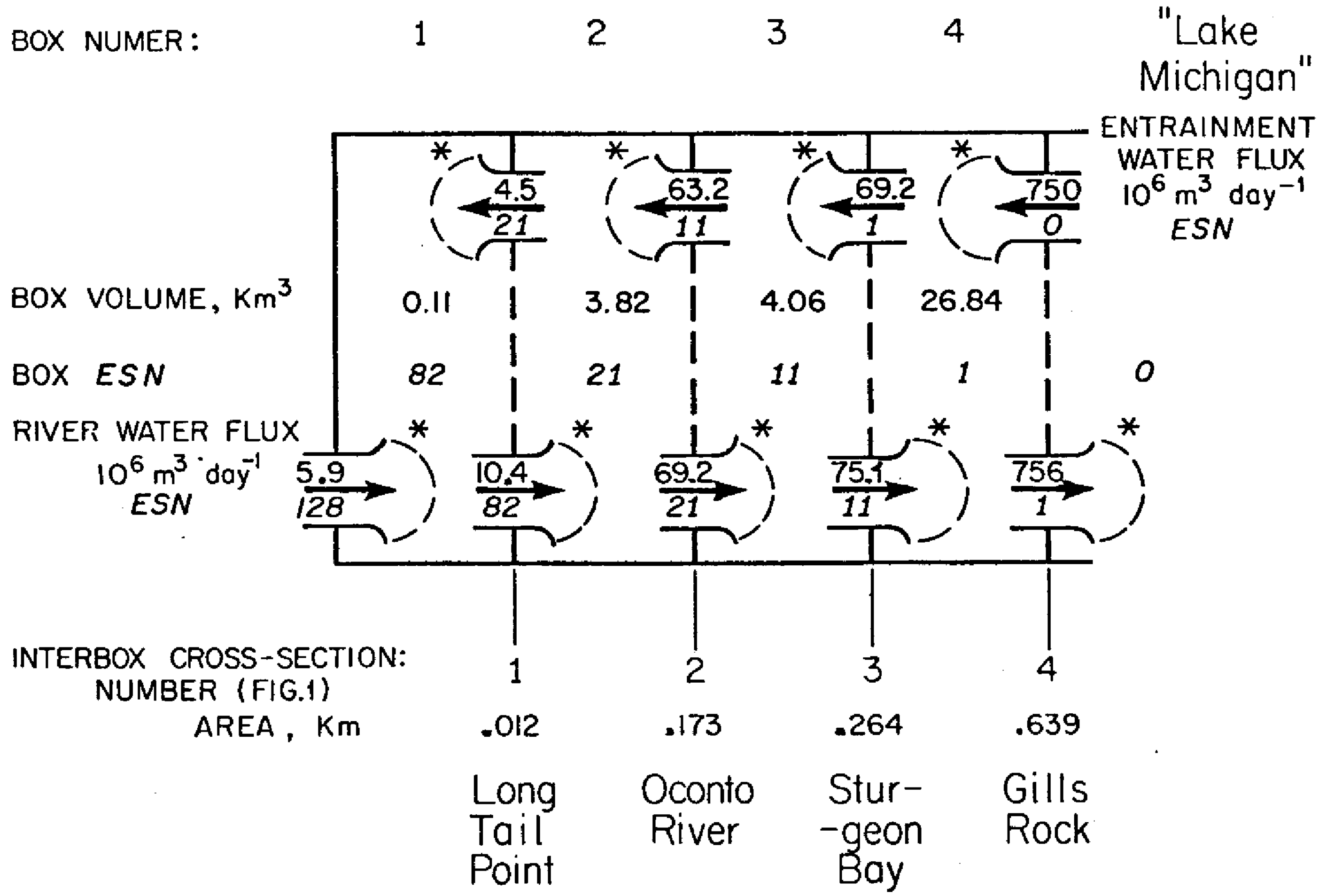


Fig. 10: Box representation of Modlin and Beeton's (1970) model of the flux and dilution of Fox River water in Green Bay during 1969. Details of the structure are discussed in the text. The fluxes of progressively diluted river water and of (Lake Michigan) entrainment water are shown separated respectively in the lower and upper row of interbox "conduits". Asterisks serve to recall that the outflow from each conduit is immediately and completely mixed into the receiving box.

Legend for figure on previous page.

Fig. 9: Spectra of water level fluctuations based on two months of 15 min average levels at GB, Green Bay city (July–August, 1961; January–February, 1963, under ice), 44 days of 30 min average levels at ES, Escanaba (August–October, 1953); and three months of 30 min average levels at PI, Plum Island (August–November, 1969). Numbered, unbroken vertical lines are placed at the frequencies identified as those of "observed" oscillations corresponding to the Green Bay modes. Lettered, broken vertical lines are those identified with Lake Michigan main basin modes. (from Rao, Mortimer, and Schwab, 1976).

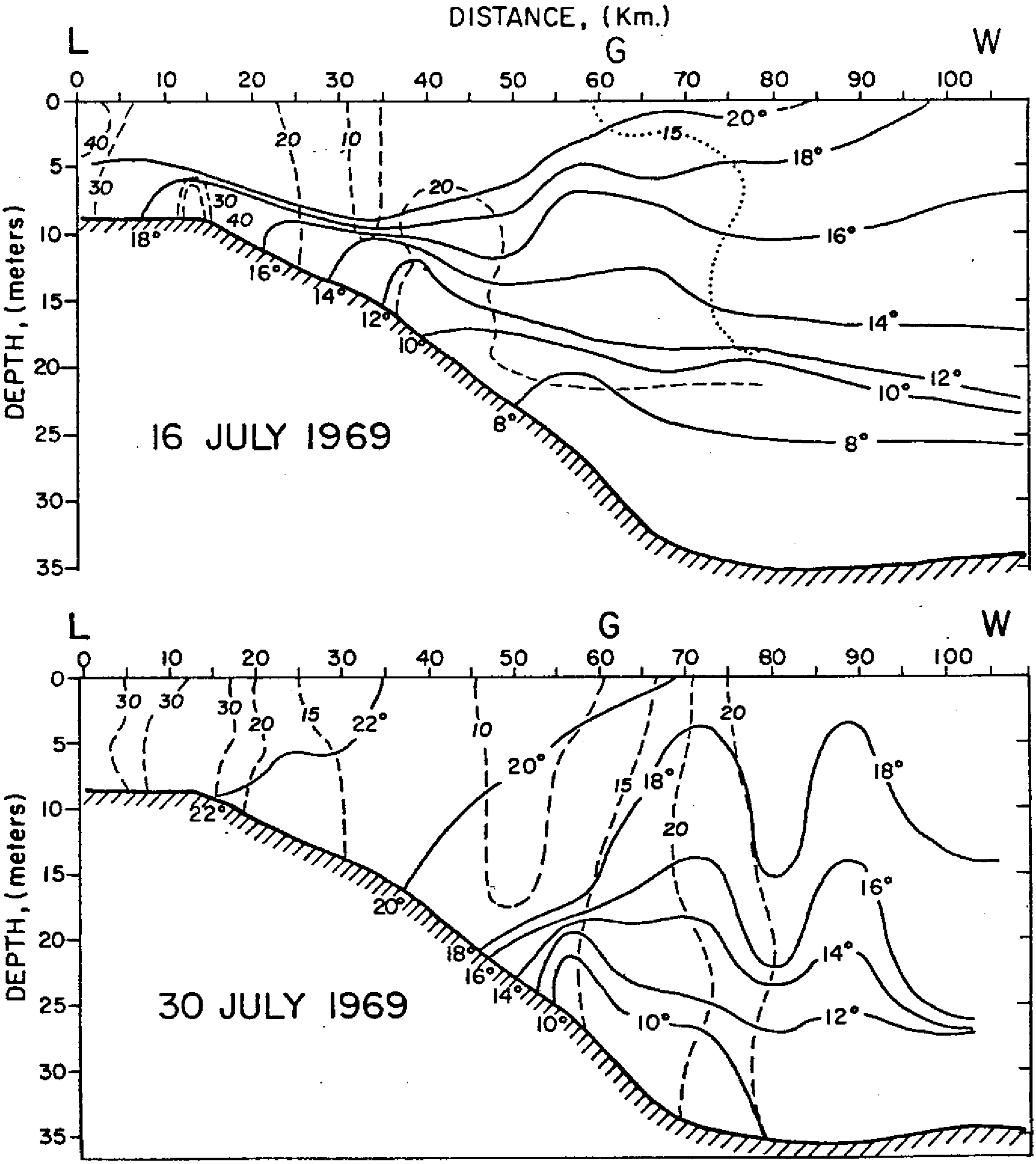


Fig. 11: Distribution of temperature (^{o}C) and electrical conductivity (expressed as % volume of Fox River water) in longitudinal sections of Green Bay on 16 and 30 July 1969 (redrawn from Ahrnsbrak 1971). Letters L, G, and W refer to correspondingly labelled positions in Figure 1.

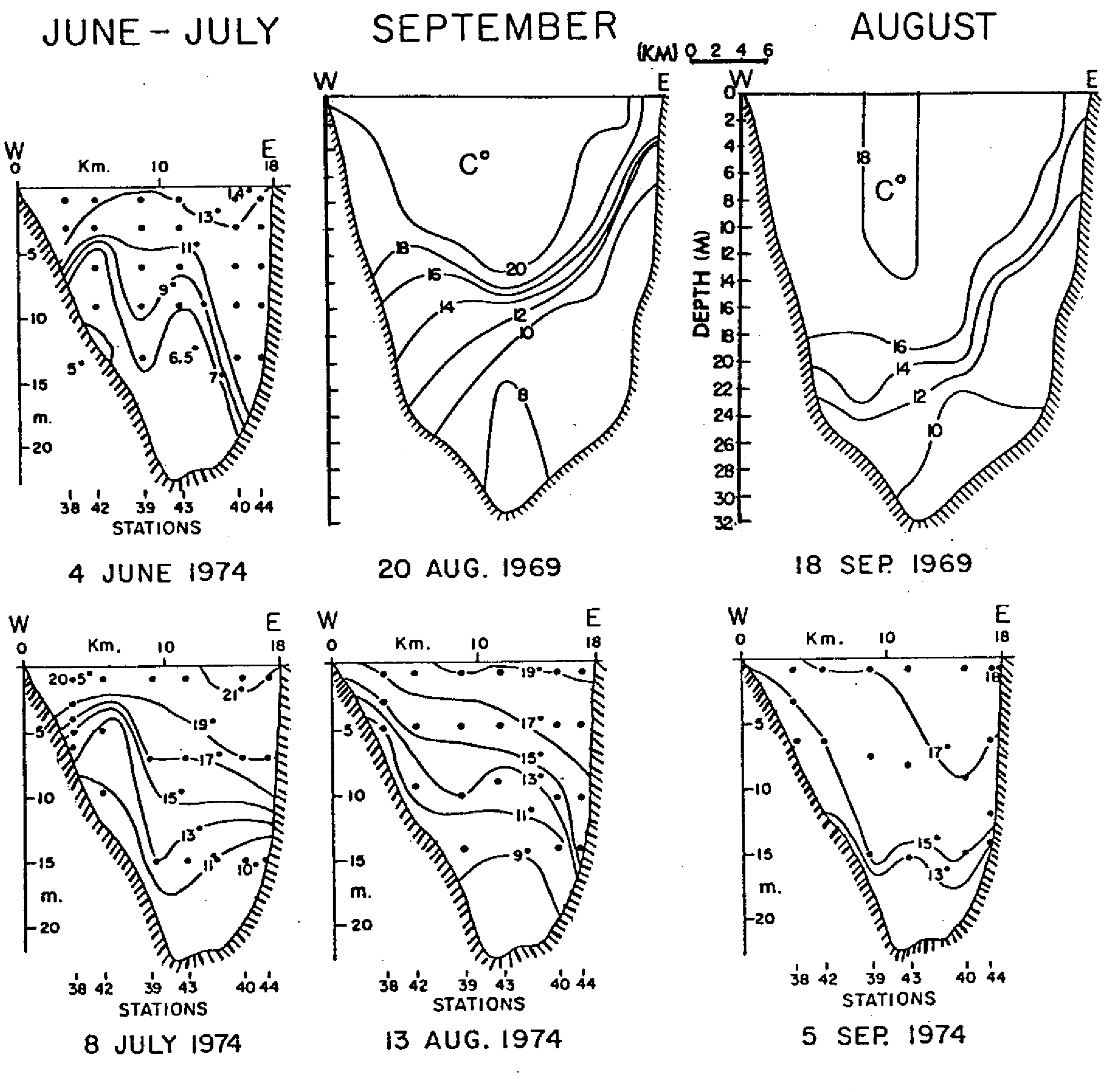
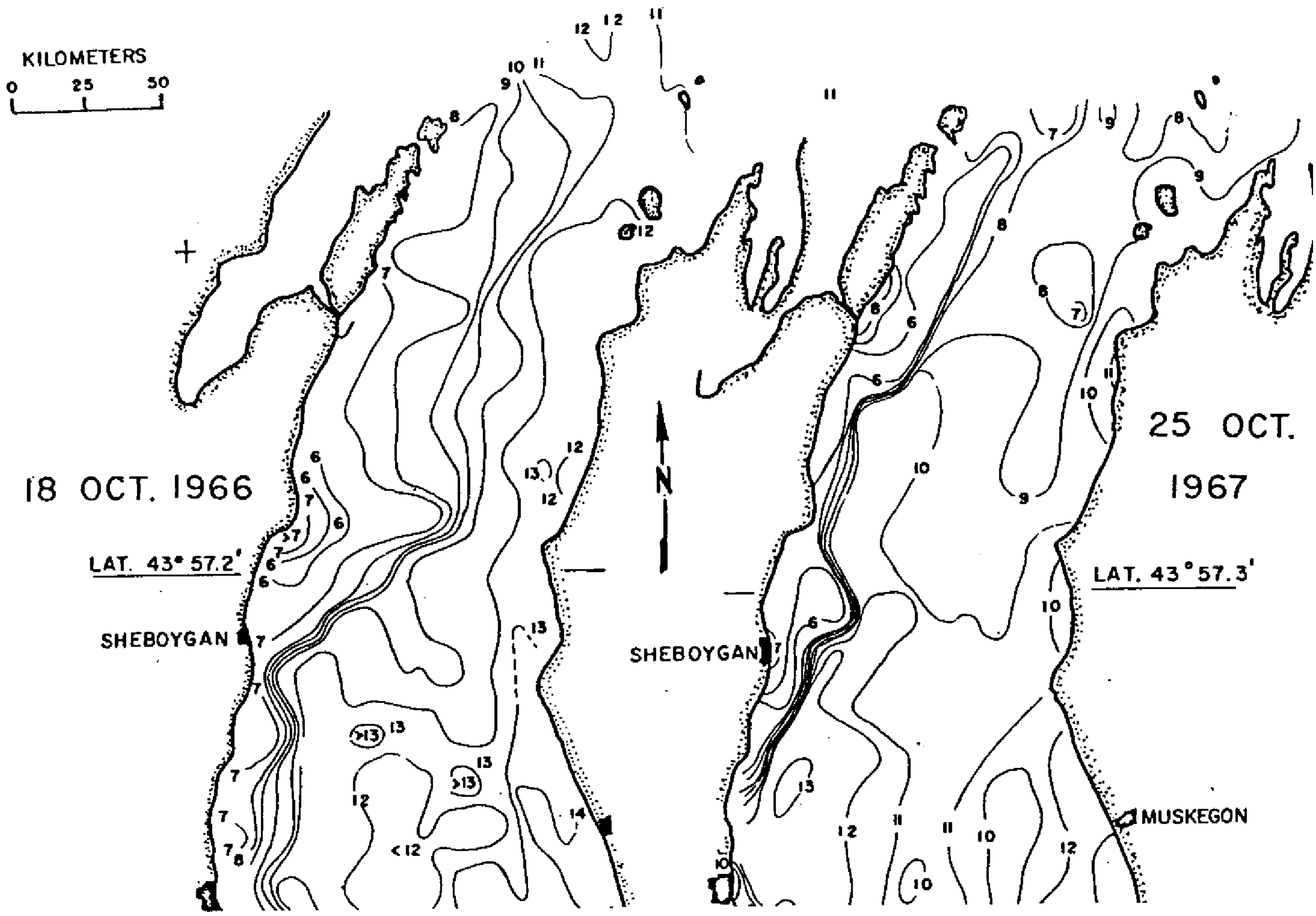


Fig. 12: Distribution of temperature (^{o}C) in cross-sections of Green Bay on 20 August and 18 September 1969 (Ahrnsbrak 1971, Section IV, Fig. 1) and on four dates in 1974 in a section situated between sections II and 3 in Figure 1 (data from Patterson et al. 1975).



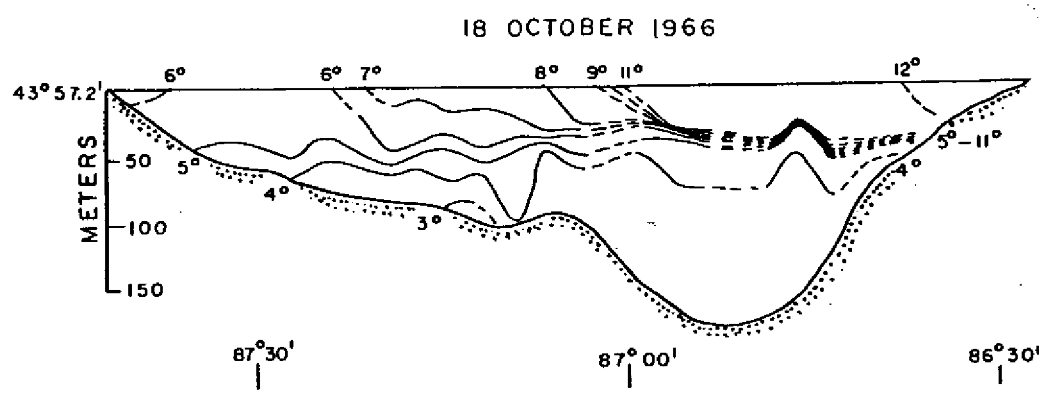


Fig. 13: Distribution of temperature (°C, by airborne themometry) at the surface and in a Lat. 43° . 57 ' cross-section of Lake Michigan in October 1966 and 1967 (redrawn from Noble and Wilkerson 1970).

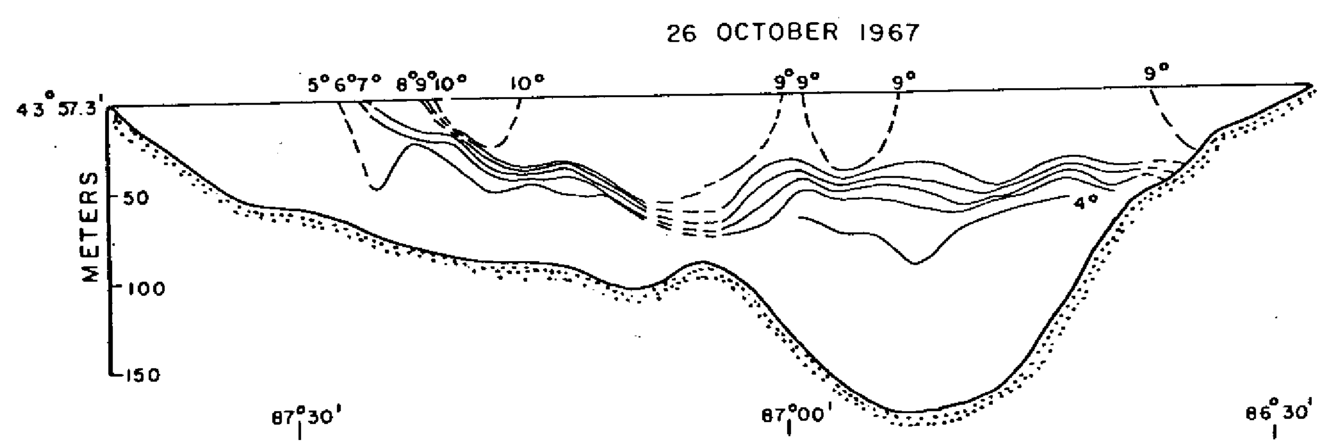


Fig. 13 legend above.

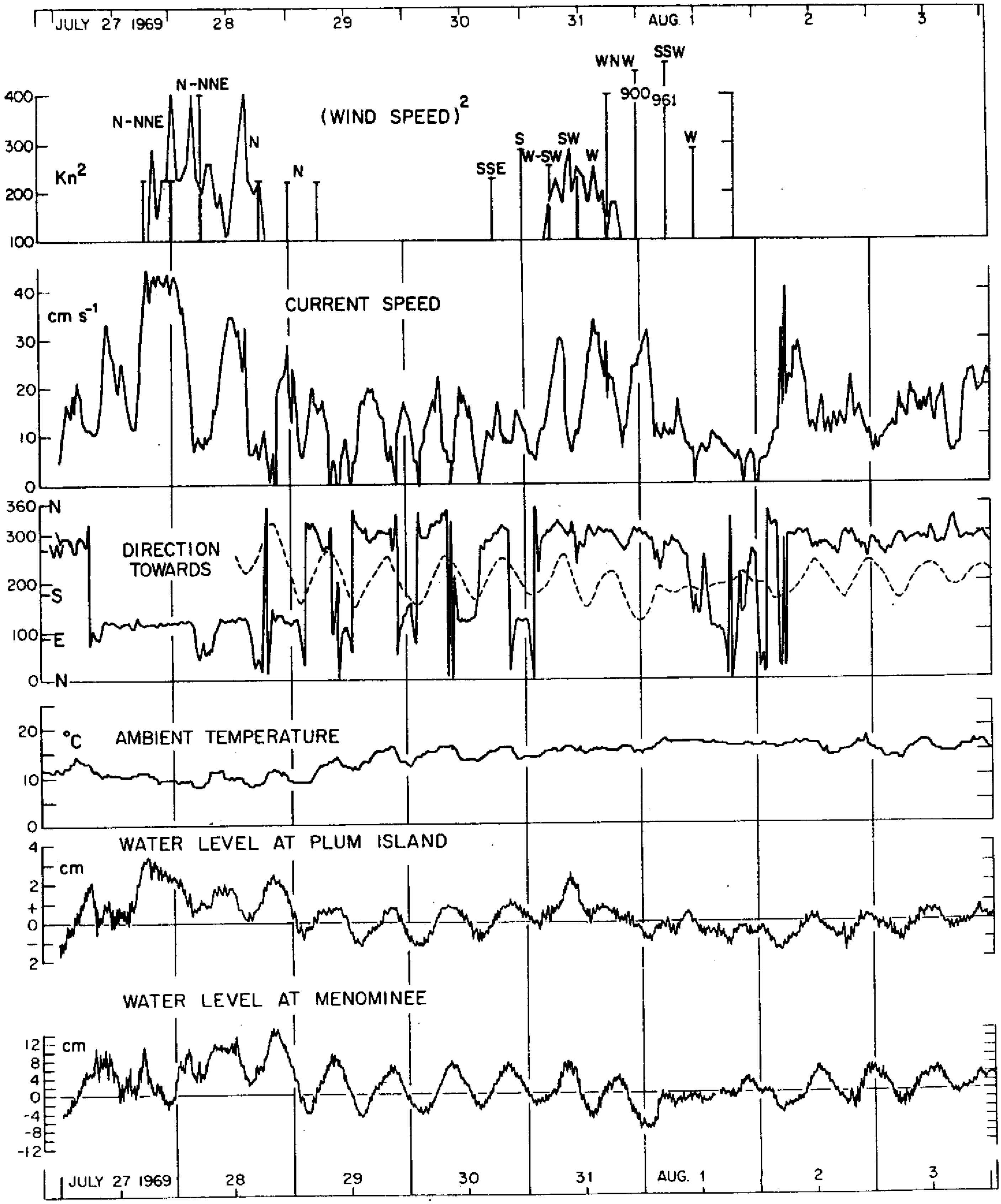


Fig. 14: Current speed and direction at a mid-water station (15 m depth, position indicated by asterisk in Fig. 1) in the Death's Door Passage between Green Bay and Lake Michigan. Also shown is water level at nearby Plum Island and at Menominee (P and M, respectively, in Fig. 1) and wind speed (in exesss of 9 knots and squared) at Green Bay Airport and Plum Island. The elevation scale of the Plum Island level record is just over twice that of the Menominee record. The latter is superimposed, as a broken line on the direction record.

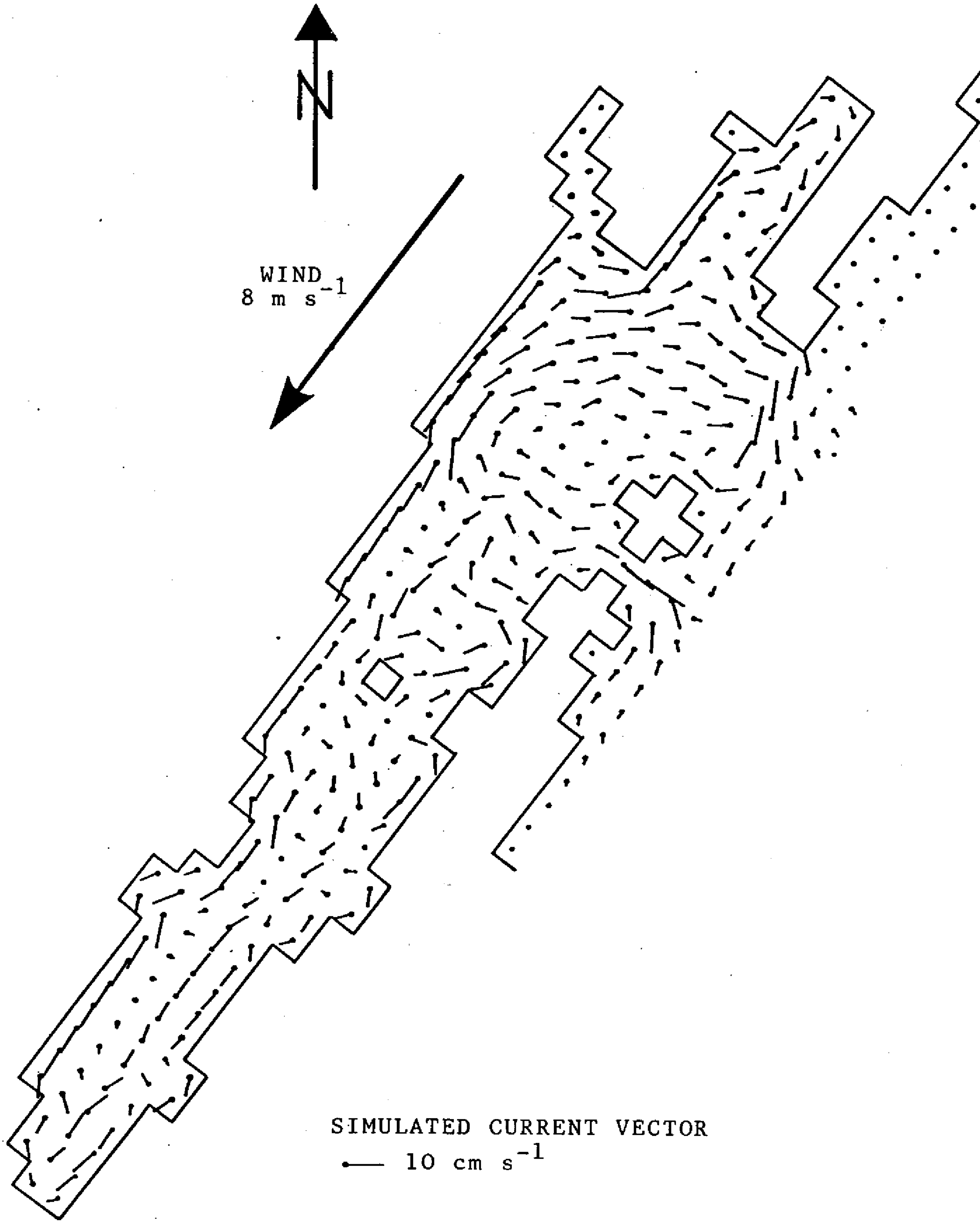


Fig. 15: Green Bay and northern Lake Michigan (not shown); distribution of current predicted by a model described in the text (Heaps, Mortimer and Fee, unpublished) after a steady wind (uniformly distributed over the Bay, with no wind over the main Lake) has been blowing at 8 m s^{-1} from N 38° for 40 hours. The corresponding distribution of water surface elevation is illustrated in Fig. 7.

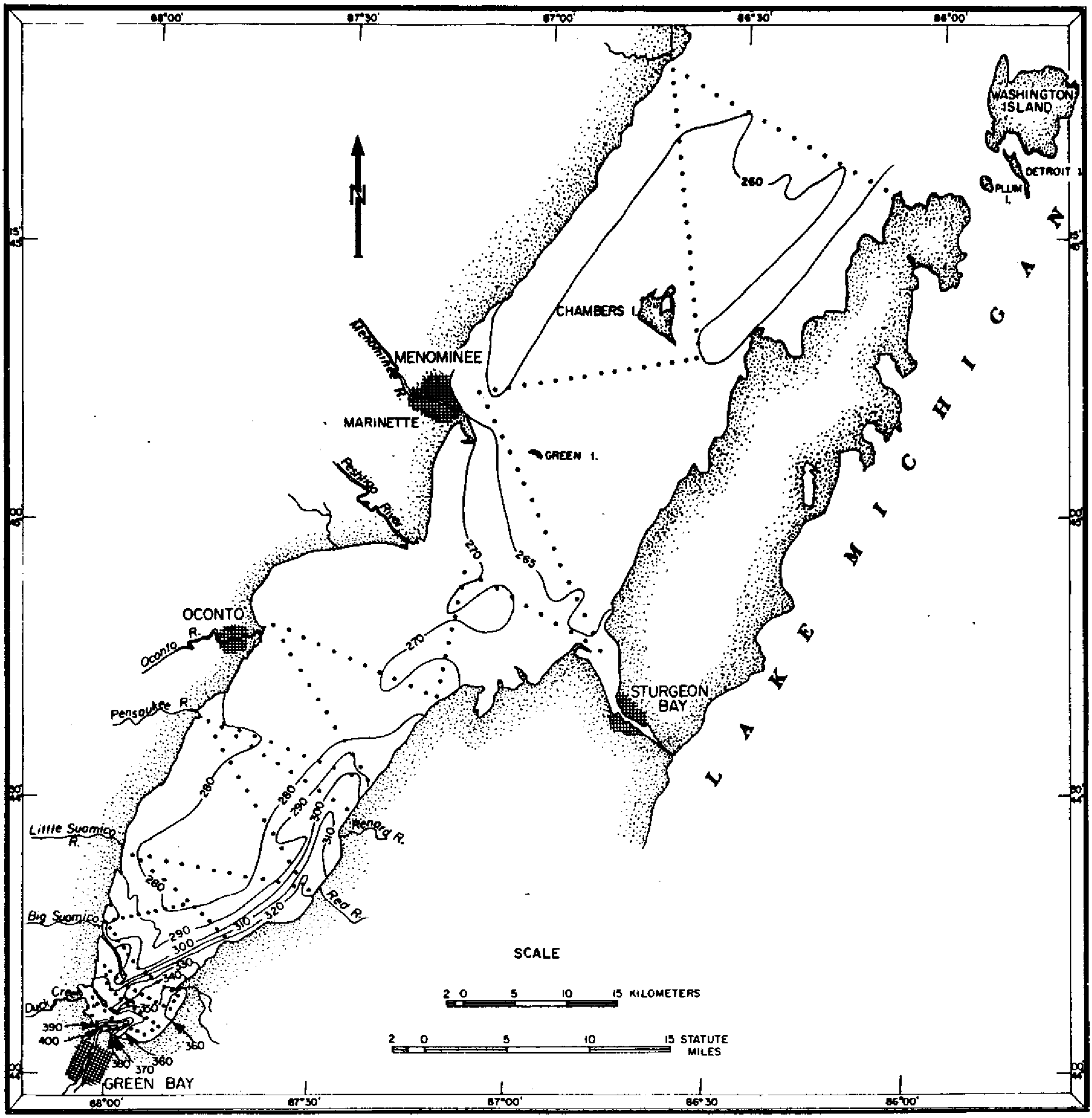


Fig. 16: Distribution of conductivity, in μmhos at 25°C, in Green Bay, determined on 23 July 1968 by Modlin and Beeton (1970).

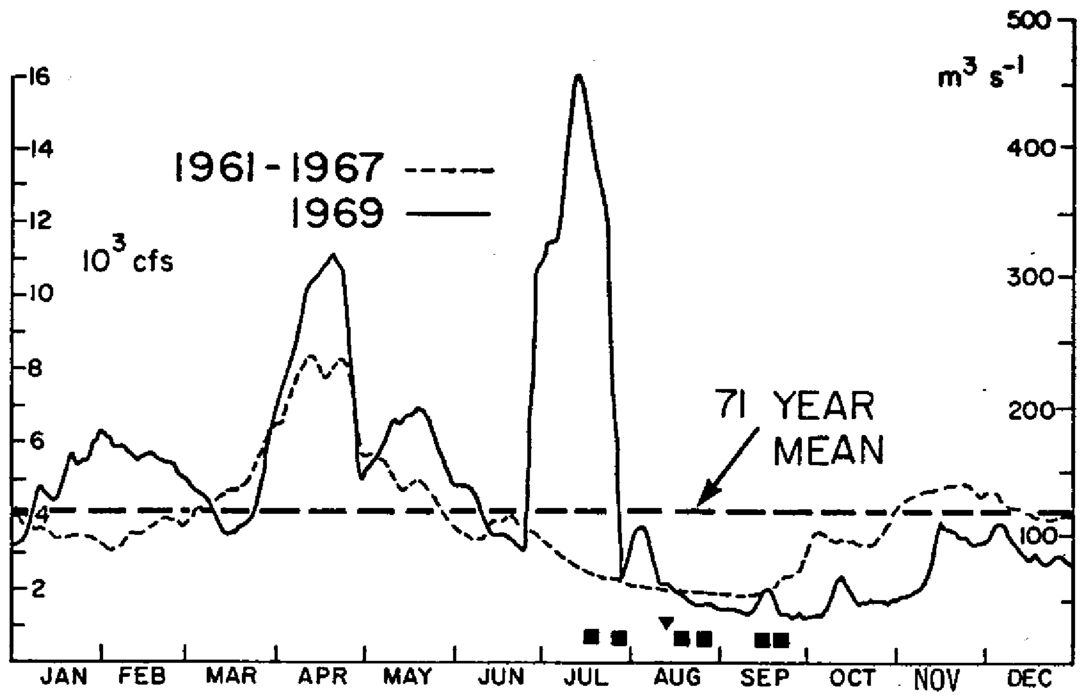


Fig. 17: Discharge of the Fox River (5-day running mean of daily rates, redrawn from Ahrnsbrak 1971) for 1969 (unbroken line) and for the 1961-67 average (broken line). Also shown, as a horizontal line, is the 71-year mean (Great Lakes Basin Commission, 1976). The squares and triangle respectively indicate the dates of Ahrnsbrak's and Modlin and Beeton's surveys in 1969.

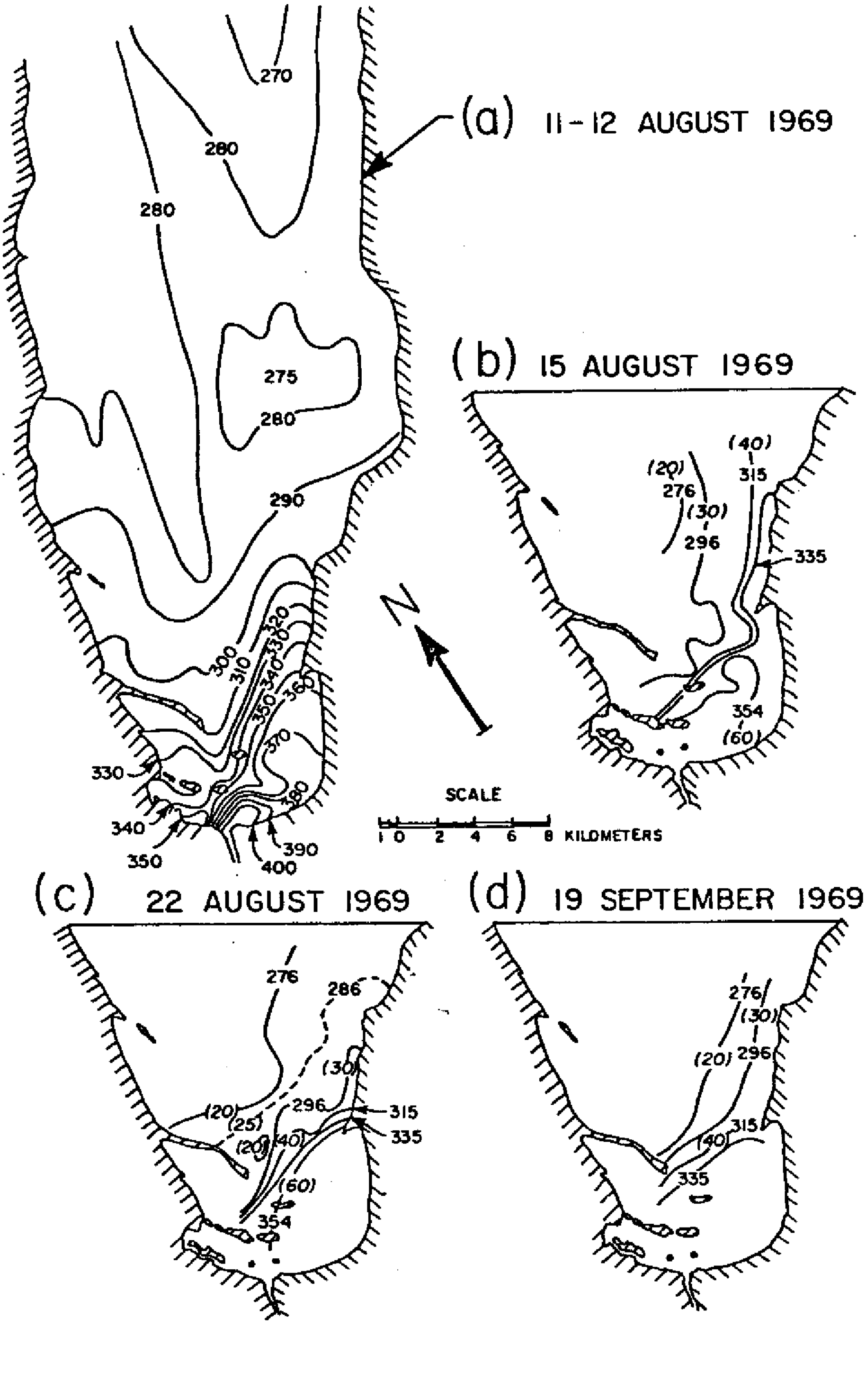


Fig. 18: Lower Green Bay 1969: Distribution of electrical conductivity (μ mho at 25°C): (a) 11-12 August (Beeton and Modlin 1970); (b), (c) and (d) on the dates indicated (redrawn from Ahrnsbrak 1971). The bracketed numbers are those given by Ahrnsbrak for river water content (% volume). These are here converted to conductivity using Ahrnsbrak's graph relating % volume to conductivity (μ mho at 18°C) and Smith's (1962) factor for converting 18° to 25° conductivity in Lake Michigan water.

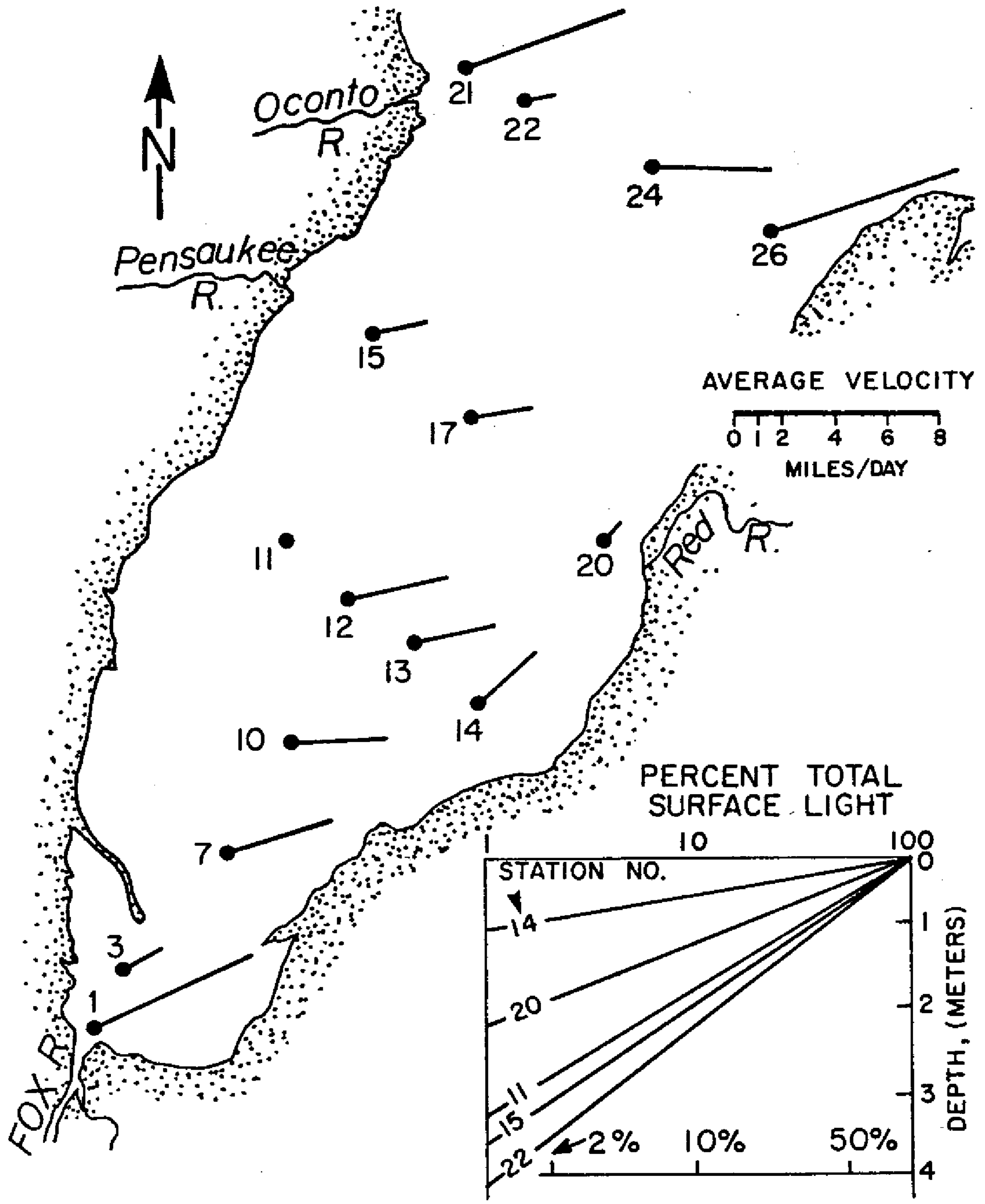


Fig. 19: Green Bay, July 1971: Direction and average velocity of drift bottles after release from the stations indicated. None released at Station 11 were recovered; and only one was recovered from Station 15. All recoveries were on the eastern shoreline. Also shown is light penetration (extrapolated extinction coefficients) at various stations, numbered as for the drift bottle experiment. (re-arranged from Howmiller and Beeton 1971)

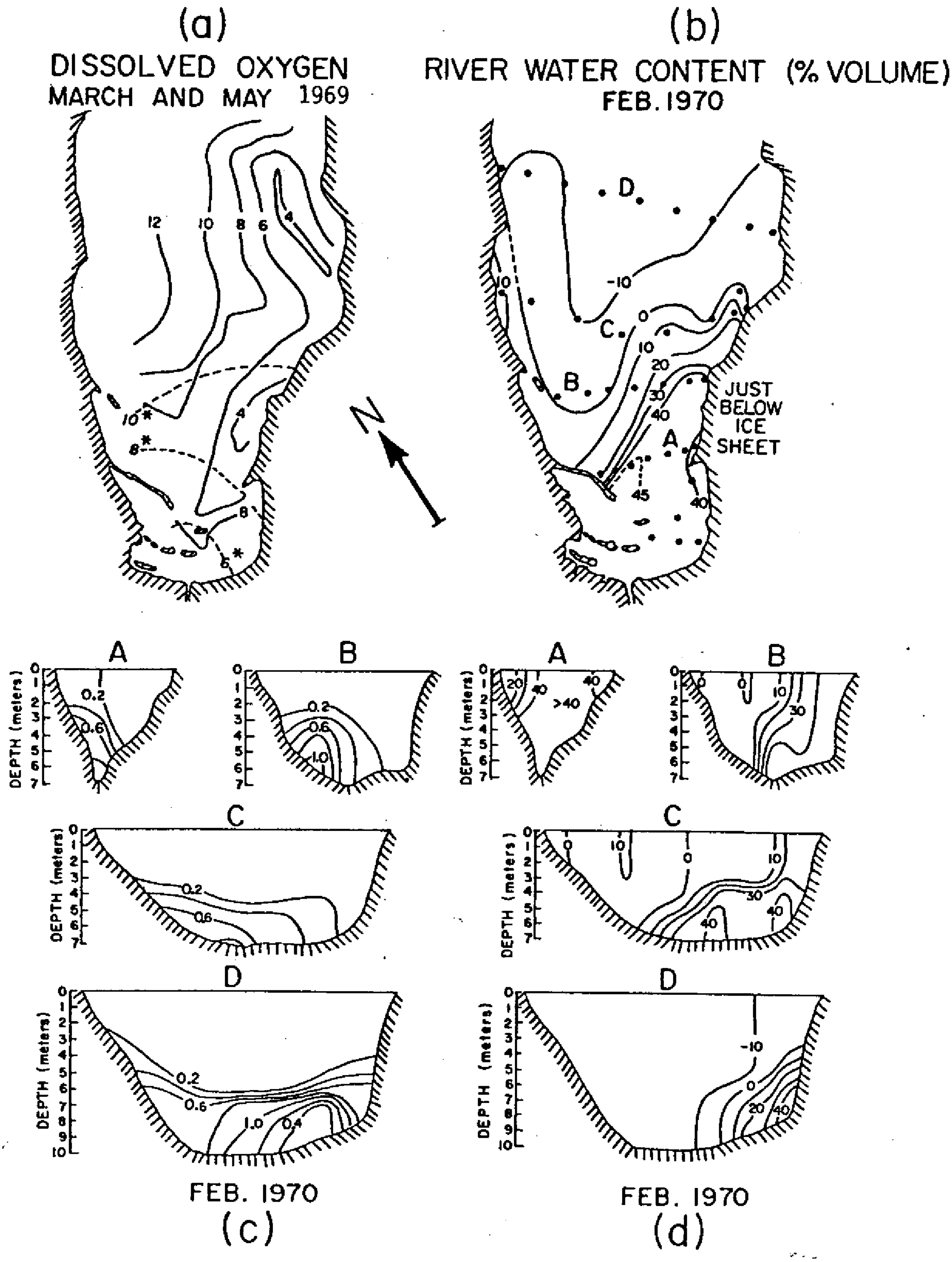


Fig. 20: Conditions under ice cover in Lower Green Bay: (a) horizontal distribution of dissolved oxygen (parts per million) 20–21 March 1969 and 18–19 May 1969 (redrawn from Epstein et al. 1974 with the May contours shown broken, with concentrations asterisked); (b) and (d) horizontal and vertical distributions of % river water (by volume) 18–19 February, computed from conductivity just below the ice sheet and in cross-sections indicated by letters (redrawn from Ahrnsbrak 1971); (c) distribution of temperature (^{o}C) on the same cross-sections (Ahrnsbrak 1971).

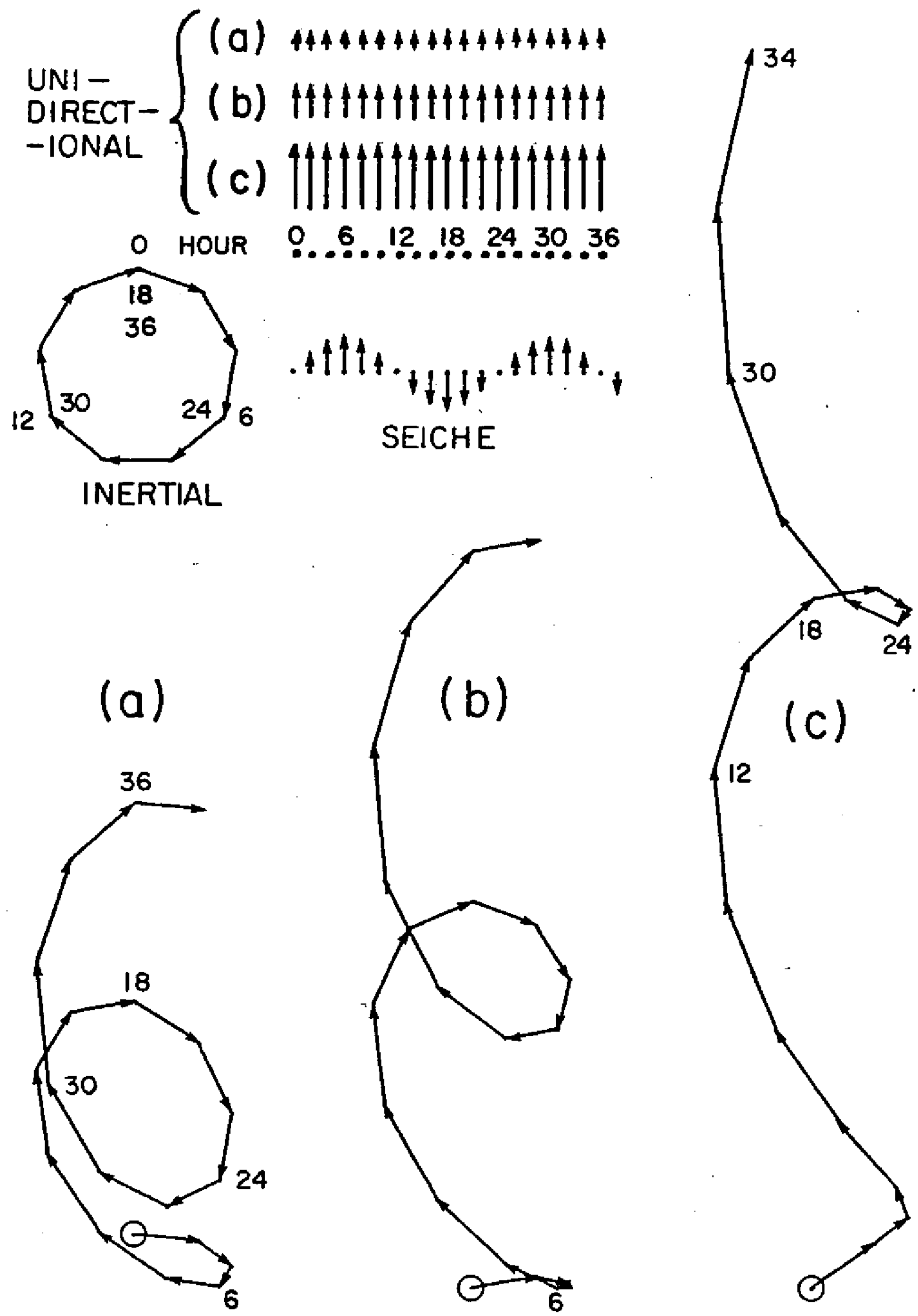


Fig. 21: Vector combination of a rotating inertial current of speed unity, a seiche current of maximum speed $\pm$ 0.5, and unidirectional current components of three speeds: (a) 0.25; (b) 0.5; (c) 1.0. The inertial period is set at 18 h, the seiche period at 12 h; and the vectors are combined every 2 h to produce progressive vector diagrams.

THE IMPACT OF LAND USE ON WATER QUALITY IN THE LOWER-FOX-GREEN BAY REGION

Basil M. H. Sharp

Daniel W. Bromley

PREFACE

As policy makers and researchers begin efforts to understand man's impact upon the Green Bay region--which includes the Bay, as well as the Lower Fox River Basin--it is imperative to start by focusing on the supply of nutrients which enter the aquatic environment. This paper--prepared especially for the Green Bay Research Workshop--is intended to provide background material whereby that problem area might be comprehended. It is not intended as a definitive research document, nor does it presume to be exhaustive. It was prepared in a very brief time to provide certain information thought useful for Conference participants to assist in the identification of important research areas pertaining to improved environmental quality in the Green Bay region. We hope that it serves that purpose.

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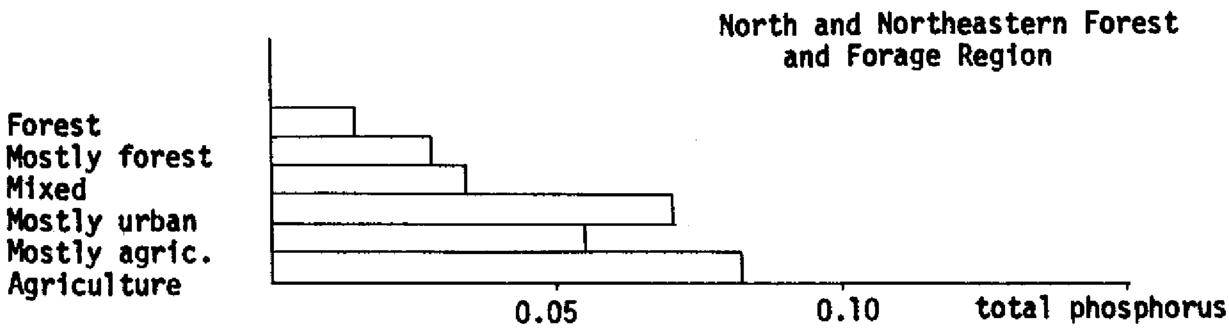
I. INTRODUCTION

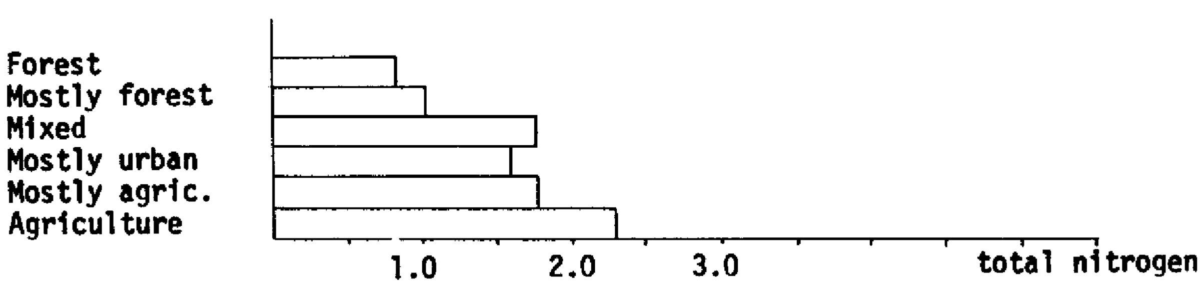
It has been well documented that the natural process of eutrophication (Nutrient enrichment) can be modified by human actions. These activities, which are usually characterized in terms of industrial growth, intensive agricultural production and increased recreational use, contribute to excessive nutrient enrichment (cultural eutrophication) which causes undesirable changes in plant and animal life, thereby reducing the quality of water resources. Activities of this nature compound the already on-going natural eutrophication of lakes and estuaries.

In general, nutrients can enter a receiving body of water from external or internal sources. Surface and groundwater components of the hydrological cycle provide the transport vehicle which links the nutrient-generating activity of people with the eutrophic state of the receiving body. These sources are external in the sense that the influx is controllable compared with the internal nutrient sources which involve sediments in place. The complexities of internal nutrient cycles and the limited controllability of such a process virtually mandates the need to control the influx of nutrients from external sources (Uttormark et. al., 1971).

A nationwide survey of the relationship between land use and stream nutrient levels concluded that nutrient concentrations (total nitrogen and total phosphorus) are generally proportional to the percentage of land in agriculture, and inversely proportional to the land in forestry (Omernik, 1977). On the basis of these concentrations, it was concluded that phosphorus was the limiting nutrient, since it is generally the limiting nutrient, as long as the N:P ratio exceeds 14:1 (Vollenweider, 1968). These results are illustrated in Figure 1.

Figure 1: Mean Total Phosphorus Concentrations and Mean Total Nitrogen Concentrations (mg/l) Versus Land Use





Source: Omernik (1977)

This study also found that the mean proportion of inorganic nitrogen increased dramatically with the agriculturally related land use, reflecting the use of inorganic nitrogenous fertilizers and the high solubility of inorganic nitrogen compounds. The above empirical results are only but a fraction of the evidence supporting the relationship between land use and the progressive deterioration of water quality due to luxuriant plant growth (Vollenweider and Dillon, 1974; Loehr, 1974).

At the watershed level the correlation between land use and nutrient loadings have also been well established. For example, the nutrient sources for Lake Mendota, Wisconsin, listed in Table 1, indicate that rural runoff contributes the major portion of total phosphorus and total nitrogen entering the Lake. Shridan and Lee have estimated rural runoff to be a major contributor to the total phosphorus loading for the Fox-Wolf River (1974). Their estimates are listed in Table 2 where rural sources are shown to contribute 33% of the total phosphorus influx. As efforts to control municipal and industrial wastewater discharges intensify, it is apparent that the relative contribution of rural areas will increase.

There is, therefore, rather compelling evidence that land use patterns reflect the nutrient loadings that enter a region's water ways, the Lower Fox-Green Bay (LFGB) area being no exception. Moreover, this appears to be particularly true if a large fraction of the hinterland is devoted to agriculture. The major objective of this study is to analyze the water quality implications of current agricultural practices in the LFGB area. We shall be focusing upon three pollutants: namely sediment, phosphorus and nitrogen.

It is important to appreciate at the outset that a rural land use pattern is nothing but a partial snapshot of an agricultural production process and it is the practices which lead to this configuration of land use that are the

Table 1: Percent Contribution of Estimated Nutrient Sources for Lake Mendota, Wisconsin

Source	Total Nitrogen	Total Phosphorus
Wastewater discharges	1.0	2.0
Urban runoff	6.0	14.5
Rural runoff	44.0	63.0
Atmospheric precipitation	6.0	2.0
Dry fallout	11.5	6.5
Groundwater seepage	12.5	0.5
Base flow	11.5	11.5
Nitrogen fixation	7.5	0.0
Woodland runoff	0.0	0.0
Marshland drainage	0.0	0.0

Source: Sonzogni (1974)

Table 2: Estimated Phosphorus Sources for the Fox-Wolf River

Source	Annual Load (lbs.)	Percent Estimate
Municipal and industrial wastewater	1,515,000	62.5
Urban runoff	95,800	3.5
Rural runoff	822,000	33.5
Precipitation	12,700	0.5
Groundwater	--[1]	--
TOTAL	2,445,500	100.0

Source: Shridan and Lee (1974)

[1]Not estimated.

major determinants of areal loadings. Consider the mixed crop-livestock system illustrated in Figure 2. Here the pattern of land use, expressed in acres of oatland, cornland and hayland is viewed as an intermediate output in a larger and more complex production process. Similarly, the number of livestock in this system provides a very limited view of the decisions that are made which lead to this particular configuration. Research which relates these aspects of the production process is important in establishing the existence of a correlation between livestock numbers and acres of crop land with nutrient concentrations. Yet, this only establishes an association and an explanation, however partial, can only be obtained by considering the practices on the land. That is, we need to know what tillage systems are in use, the current fertilizing and manure spreading practice, the manner in which crop residues are handled and so on. This is vital knowledge because we first must understand the factors which enhance nutrient export in order to design policy to control these sources.

The flow diagram presented in Figure 3, which summarizes the stages of the eutrophication process, provides the framework that will be utilized in our study of the LFGB area. Here, the eutrophication process is assumed to consist of four stages. The first relates to the factors which initiate the process, such as cropping and manure spreading, which results in a vector (3 dimensional in our case) of pollutants G. These pollutants must then be transported, or delivered, to a water channel, and we have identified this by the function d. The delivered pollutants D are then shown to enter and determine the quality W of the receiving body of water (the Lower Fox-Green Bay system).

At each stage of this process there exist a number of management opportunities which can reduce the flow of nutrients and sediment into the

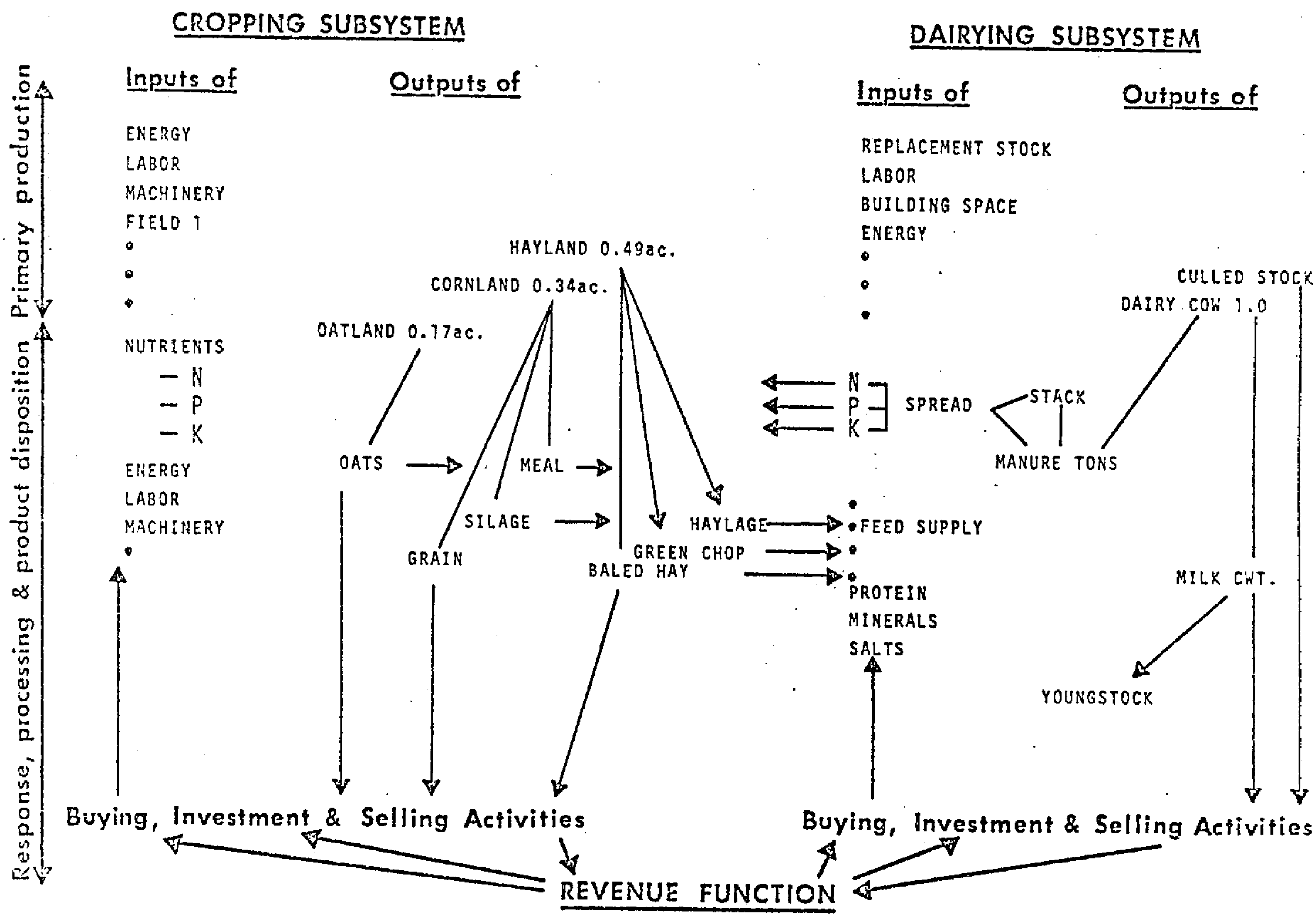


Figure 2: Production Interdependencies in a Mixed Crop-Livestock System

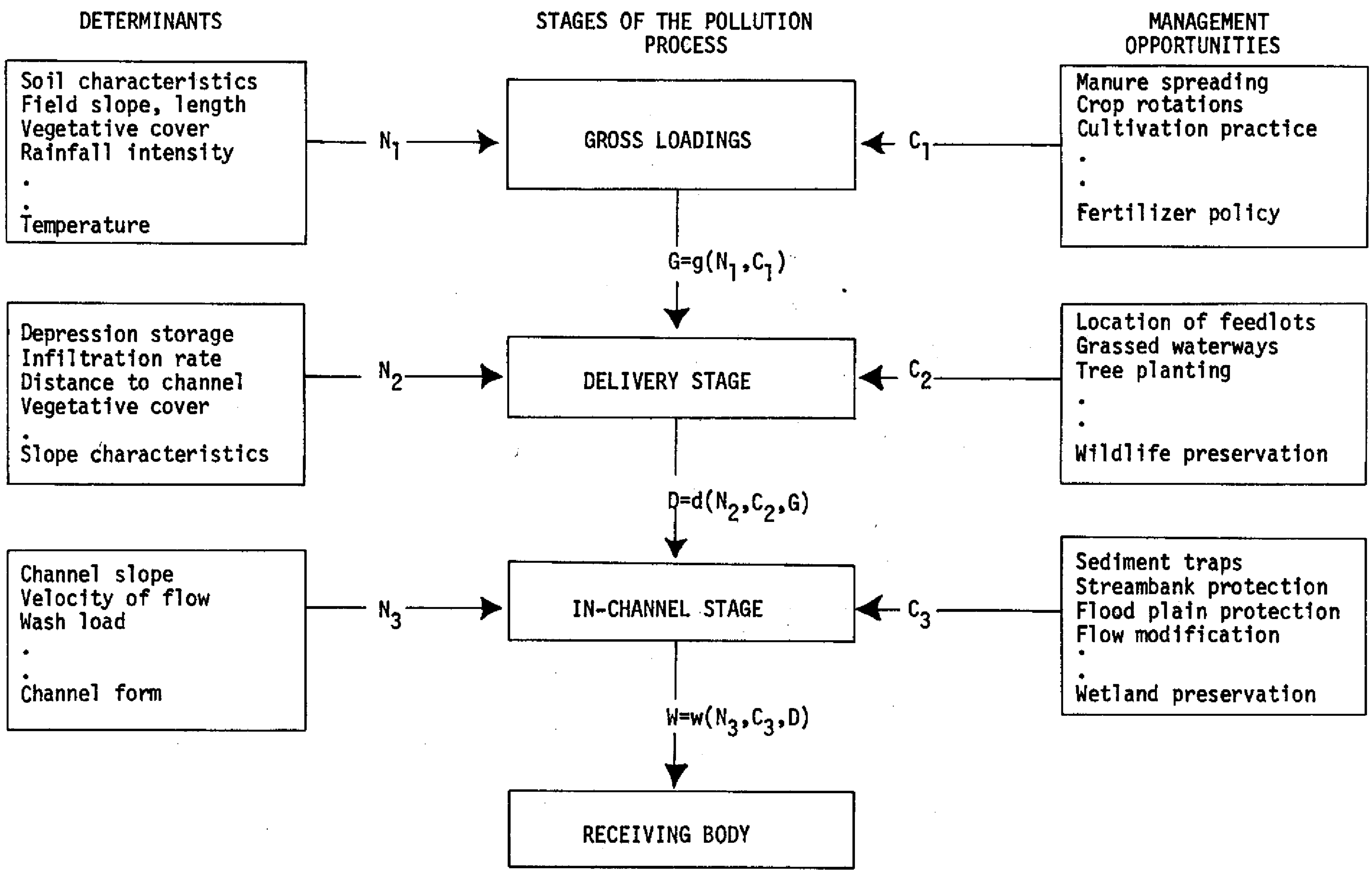


Figure 3: The Pollution Process

receiving bodies. We have identified these as control vectors (C_j) with the subscript ($j = 1, 2, 3$) referring to the stage at which the controls are implemented. In the discussion that follows, we shall be analyzing the first stage of this process only; the later stages will be the focus of our future research.

Nutrients can be transported to lakes and streams by dry fallout, precipitation, surface runoff, groundwater, and other miscellaneous sources such as wildlife. Unfortunately, the contribution of groundwater sources to eutrophication is poorly understood, as is the degree of influence a groundwater system may have upon surface water. While the linkage remains tenuous, it is apparent, in Wisconsin at least, that the boundaries of the groundwater basins correspond reasonably well with the surface water basins.

In this study we will be focusing upon the surface water component of the hydrological cycle, as it is the primary mode of transport for sediment and nutrients. The implications that land use have for water quality are best defined when the pathway consists of perennial streams; when intermittent streams become involved, the linkage between agricultural activity and water quality becomes tenous. However, given the data base in existence, it is possible to make inferences on the basis of loading potential, which is the first phase of our study.

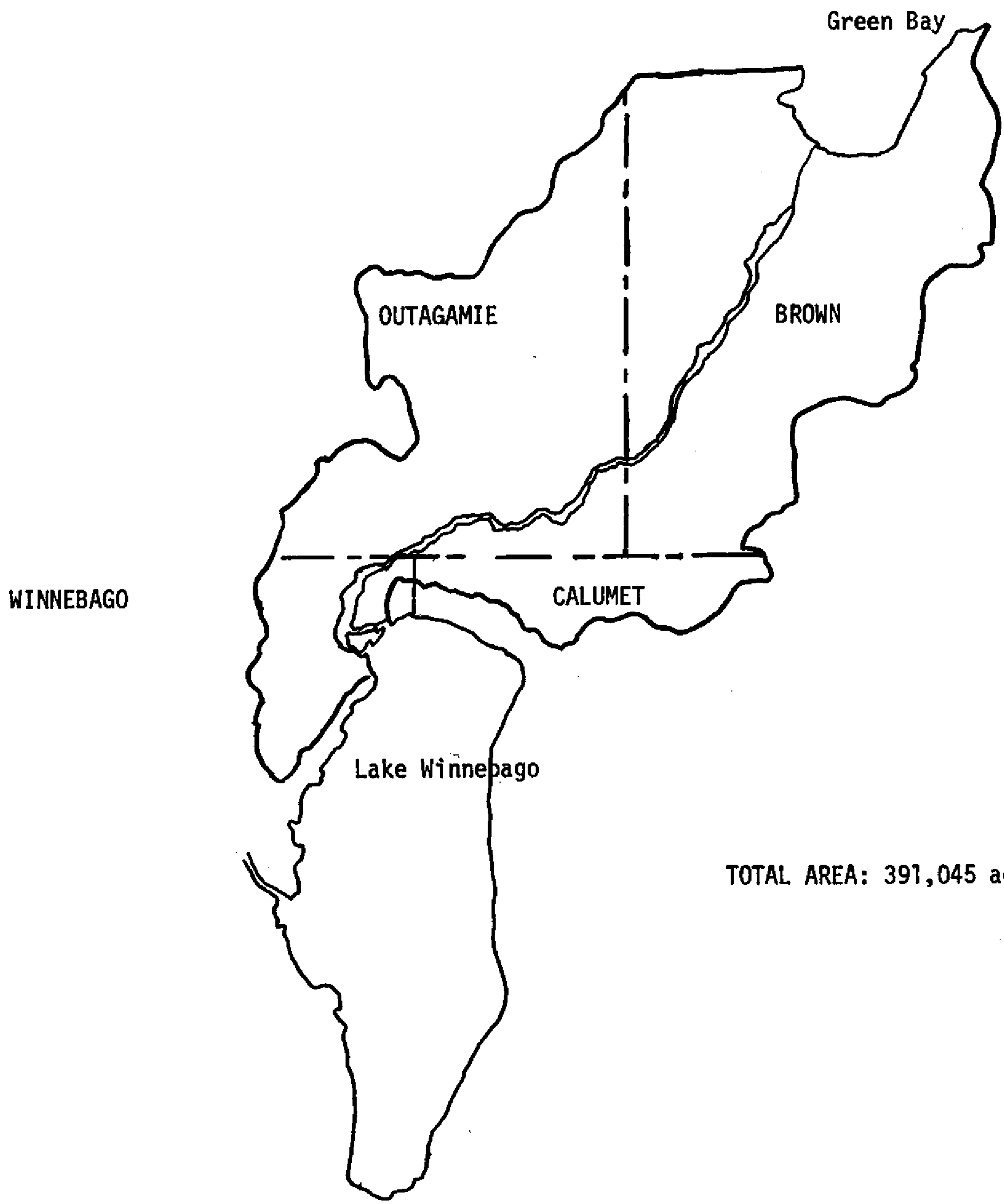
LAND USE

The Physical Setting:

A map of the study area is given in Figure 4. The region is located in East Central Wisconsin; it comprises 391,045 acres (611 square miles) and is spanned by four counties: Brown, Calumet, Outagamie and Winnebago.

The topography of the LFGB area is gently rolling with the land relief ranging from 580-800 feet above sea level. The soils are naturally fertile,

Figure 4: The Lower Fox-Green Bay Watershed



TOTAL AREA: 391,045 acres

Source: Fox Valley Water Quality Planning Agency having been derived from glacial till and outwash deposits, this inherent fertility is enhanced by agricultural activity and, as to be expected, stream fertility is higher where soil fertility levels are high. While the soils have a high erodibility potential, the topographic features of the region mitigate against the realization of this potential.

Although precipitation is the most important source of water in the regions perennial streams derive their baseflow from groundwater while intermittent streams derive their flow from surface runoff. Drainage patterns and runoff rates are influenced by the topographical features of the land surface which in turn is closely related to the topography of the bedrock. The underlying bedrock consists mainly of dolomite, while some areas in the eastern part of the basin contain some shale rock.

Peak flows of water are typically registered in March/April, a time when the ground is frozen and infiltration rates are minimal. A second peak may occur in June during years of high precipitation. The mean precipitation is 28.45" per annum, 56% of this falls during the months of May through September, with June being the wettest month with 4.3" of rainfall.

The Land Water Interface:

An indication of the impact that cultural activity is likely to have on the region's waterbodies can be obtained from analyzing shoreland uses. The miles of shoreland use for the LFGB area are presented in Table 3. Shoreland is defined here as the land within 1,000' of either bank, or edge of a lake, with lakes and impoundments representing waterbodies of at least 25 acres and streams being limited to those which are named perennial streams (Shoreland Use in Wisconsin, 1977).

Agriculture is directly associated with 50% of the shoreland in the study area, while low-density development and urban use comprise 24% and 17% of the

Table 3: Miles of Shoreland Use in the Lower Fox River Basin

USE	URBAN	LOW DENSITY DEVELOPMENT	AGRICULTURAL	UNDEVELOPED	TOTAL
Inland lakes	4.45	4.64	0.43	3.59	13.11
Streams	45.16	63.02	156.83	19.76	284.77
Great lakes	3.91	8.02	0.00	2.56	14.48
TOTAL	53.52	75.68	157.26	25.91	312.36

Source: Shoreland Use in Wisconsin, Wisconsin Department of Natural Resources, 1977

total use, respectively. This use pattern persists for perennial streams; however low density development and urban landuse predominate along lake shores. The close correlation between agricultural land use and perennial streams is important, since streams are responsible for the transport of pollutants to Green Bay. Furthermore, the potential for accelerated shoreline erosion is enhanced when livestock operations concentrate near streams.

Wetlands are an integral part of the hydrology cycle and they are commonly found along slow meandering streams or close to lakes where streams enter. These areas are not clearly either land or water, since the water level remains just below, at or just above the surface of the soil for a significant part of the year. Wetlands play a functional role in the maintenance of water quality as they remove sediments and nutrients from the flowing water. Low gradients enable the sediment to settle out and the wetland vegetation removes soluble nutrients such as nitrates and phosphates. Currently,there are approximately 15,030 acres of wetland in the LFGB area.

Land Use & Cropping Patterns:

A breakdown of the land area is given in Table 4. The most striking feature of the classification is the high proportion of the total land mass (391,045 acres) devoted to agriculture. Crop and pasture land account for 270,087 acres, or 69% of the total land area.

The implications that land use has for regional water quality parameters are summarized in Table 5. While the absolute magnitude of these pollutants will be regionally specific, these estimates do offer insights into the relative contributions that may be expected in the LFGB area. Clearly, farmland has the largest nutrient export potential, with nitrogen and phosphorus ranging from 2.4-24 lbs. and 0.92-3.88 lbs. per acre per year, respectively. Loading rates from residential, commercial and industrial land only approach the lower bounds of these estimates. In addition, the problem of surface erosion, the first step in the sedimentation process, is potentially very high for agricultural land--especially cropping land.

The cropping patterns depicted in Table 6 show a predominance of land being devoted to the production of corn (31%), hay (39%), and oats (16%). This reflects the dependence of a livestock operation upon the cropping subsystem for the provision of high energy feed supplements and forage. On a given field, the soil loss gradient runs from corn, through oats, to alfalfa which has the lowest soil loss potential. The nutrient export potential of these crops will be discussed below.

The analysis which follows will focus on three major pollutants. First, the problem of soil erosion will be discussed. Then, the contribution of agricultural activity to areal loadings of nitrogen and phosphorus will be analyzed from the perspective of fertilizer usage and animal concentrations.

Table 4: Land Use By County in the Study Area

	BROWN		CALUMET		OUTAGAMIE		WINNEBAGO	
LAND USE	%	area	%	area	%	area	%	area
Residential	7.48	14,336	4.18	1,010	7.25	10,493	14.86	4,577
Commercial	0.33	629	0.27	63	0.77	1,122	1.85	571
Industrial	1.25	2,403	0.10	26	0.78	1,133	3.22	991
Transportation	7.02	13,437	0.00	0	0.56	822	0.26	80
Communication	1.24	2,366	0.00	4	0.24	335	0.26	82
Governmental	0.45	847	0.15	34	1.58	2,294	1.06	325
Recreational	1.36	2,616	0.12	30	1.28	1,847	1.86	572
Crop land	59.58	114,124	33.10	20,096	68.17	98,524	54.83	16,878
Pasture land	7.71	14,789	0.85	207	3.45	4,976	1.60	493
Woodland	10.25	19,614	10.30	2,490	12.80	18,501	7.40	2,278
Wet land	3.33	6,369	0.90	224	3.11	4,496	12.80	3,941
TOTAL ACRES:		191,530		24,184		144,543		30,788

Source: Fox Water Quality Planning Agency Records

Table 5: Land Use and Regional Water Quality Parameters

LAND USE	Imperviousness	QUALITY PARAMETERS BOD lbs ac/yr	N lbs ac/yr	P lbs ac/yr	Erosion potential
Natural forests	low	small	0.89	0.089	low
Agricultural land	low	-	2.4-24	0.92-3.88	high
Feedlots	high	varying with animal type, density & practice			
Single family residence	low-medium	5.9	0.6	0.2	-
Multi-family residence	medium	14.0	2.5	0.67	-
Commercial	high	43	2.4	1.3	-
Industrial	very high	23.4	3.3	0.56	-
Resource extraction	varies with methodology and management				
Recreation	varies with intensity of use				
Urban and road construction	-	-	-	-	30,000-150,000 t/ac

Source: Shubinski and Nelson, 1975

Table 6: Estimated Cropping Patterns for Each County

Land Use	Brown	Calumet	Outagamie	Winnebago	Total
Pasture	14,789	207	4,976	493	20,465
Corn for grain	10,079	2,734	17,508	4,172	34,493
Corn for silage	22,165	3,322	22,060	2,037	49,584
Corn for dry fodder	134	24	257	46	461
Sorghums	353	8	28	8	397
Alfalfa hay	31,647	6,051	22,666	3,766	64,130
Other hay	22,332	3,102	15,440	2,116	42,990
Wheat	641	325	598	386	1,950
Oats	22,607	3,279	14,601	2,514	43,001
Barley	372	54	377	57	860
Soyabeans	85	155	659	712	1,611
Field seed crops	418	68	202	27	715
Peas	1,244	655	2,017	487	4,403
Sweet corn	917	202	1,329	432	2,880
Other crops	1,130	117	782	118	2,147
TOTAL ACRES	128,913	20,303	103,500	17,371	270,087

Source: Census of Agriculture, 1974

Soil Erosion and Land Use:

If has been estimated that 85% of the soil erosion in the United States occurs on cropland. From an agricultural production standpoint, an erosion rate of 3 tons per acre per year is acceptable (Peterson, 1976). However, this rate may not be conducive to stream and lake quality, especially since sediment plays a key role in the transport of nutrients, organic matter and chemicals. Sediment itself creates turbid conditions and many of the streams and lakes in the study area exhibit high levels of turbidity.

Sedimentation is a process involving three readily identifiable stages. The first stage, and the one we are primarily concerned with in this phase of our study, involves the physical detachment of soil particles by the impact of raindrops and flowing runoff, a process which Wischmeier refers to as soil loss (1976). Soil characteristics, such as those captured by the soil erodibility index, slope, field length, vegetative cover and rainfall energy are the key determinants of soil erosion.

The Universal Soil Loss Equation (USLE) provides a reasonably accurate tool to characterize the long term, average gross soil erosion levels for the region. These quantities are listed in Table 7, where the average rate of erosion is computed to range from 0.8-1.7 tons per acre per year.

The second stage of the sedimentation process concerns the transport of eroded soil to a channel; this is commonly referred to as the sediment yield. Sediment yield is, in general, inversely related to the drainage area of a basin, therefore a large area such as the LFGB region can be expected to have a sediment delivery ratio of 8-10% (ARS-USDA, 1975). We have utilized a 10% ratio in this study which results in a loading to the system of 49,737 tons (or 0.12 tons per acre) per year.

The final stage of the sedimentation process involves in-channel transport and deposition. Deposition is a temporary halting of the material in

Table 7: Rural Land Use, Gross Loss and Sediment Delivered by County

	BROWN t/ac/yr	%area	CALUMET t/ac/yr	%area	OUTAGAMIE t/ac/yr	%area	WINNEBAGO t/ac/yr	%area
LAND USE:								
Cropland	0.8	66	1.0	70	1.6	68	2.1	59
Grassland	2.5	8	0.2	17	0.4	17	0.1	6
Woodland	2.8	12	0.1	10	0.1	2	0.1	8
Other	0.3	8	0.5	6	0.1	9	0.2	22
GROSS LOSS	439,405		161,611		530,898		768,611	
PER ACRE	1.3		0.8		1.3		1.7	
DELIVERED	43,940[2]		16,161		53,089		76,861	
PROPORTION IN STUDY AREA	0.56		0.12		0.35		0.06	
LOADING TO LFGB	24,606		1,939		18,581		4,611	

Source: Conservation Needs Inventory, 1977

[1]Represents the percentage area sampled.

[2]Assume a 10% delivery ratio (ARS-USDA, 1975)

transport. Sediment is, therefore, the end product of a highly complex, and partially understood, process originating at the field level. Moreover, the complexity of the delivery and in-channel phases makes prediction of the water quality effects of land management alterations extremely tenuous.

Natural variability is perhaps the major complicating factor. In fact climatic influences on the number and magnitude of sediment generating events have been shown to explain as much as an eight-fold variation in observed annual sediment yields (Knox et. al., 1975). Man-induced variability can have either a compounding or ameliorating effect. Watershed response to heavy June rains on cornland will differ markedly from what its response would be to the same storm occuring in September. Thus, both natural and man-induced sources of variability must be simultaneously considered.

In conclusion, the average level of soil erosion, as predicted by the USLE for the LFGB region is low. It is low from a soil productivity viewpoint for sure, whether or not it is from a water quality perspective will require further analysis. Furthermore, these are average loading and a more thorough analysis must consider the distribution of soil loss. At this stage, it would appear that it would be difficult and costly to reduce the current level of soil erosion occuring at the field level. Streambank erosion, which is not considered in the USLE, may make a significant contribution considering the animal concentrations in the study area and their proximity to waterways.

Fertilizer Use:

Any substance that is added to the soil to supply plant nutrients and stimulate plant growth is a fertilizer. There are two main categories of fertilizer: inorganic fertilizers which are usually manufactured and commonly referred to as commercial fertilizer, and organic fertilizers (manures) which are essentially the residues of animals and plants. In this section we will examine the potential role that commercial fertilizers play in the eutrophication process with the view of establishing their likely contribution to area-wide nutrient loadings. The environmental implications of organic manures will be discussed in the following section.

Fertilizer use, expressed in pounds of nitrogen (N) and pounds of phosphate (P_2O_5), is presented in Table 8 for each of the four counties in the study area, at four points in time, over 15 years. In all instances, the per acre application of N has increased dramatically; in each case it has more than doubled. The use of phosphate has also increased significantly. On average, it appears that farmers in these four counties are building up the nutrient status of the soil. This conclusion is also supported by the decreasing quantities of corrective phosphate being recommended by county-wide soil analyses, which are presented in Table 9, for land in a rotation of corn-oats-hay. Maintenance requirements, which are also listed in Table 9, are more closely related to productivity levels whereas corrective requirements relate to the notion of a stock of phosphorus in the soil system.

A viable agricultural enterprise depends upon an adequate supply of plant nutrients, in addition to genetically superior plants and a host of other environmental factors such as moisture and temperature. Nitrogen (N) and phosphorus (P) are among the essential elements required for plant growth. Nitrogen, which is absorbed in the form of nitrates, is a vital nutrient due to its role in protein formation and chlorophyll; while phosphorus, which is absorbed primarily as orthophosphorus, is an essential element in energy transfer processes. The objective of agricultural operators is, therefore, to manipulate the supply of these elements so as to remove them as growth inhibiting factors in the production process.

The amount of fertilizer used will vary depending upon the crops grown, the fertility status of the soil, the rotations practiced and the residue

Table 8: Trends in Fertilizer Consumption 1959-1974

COUNTY		Acres fertilized[1]	Quantity tons	Statewide average analysis[2] % N	% P	Nutrient input lbs N	lbs P_2O_5	Nutrient input per acre fertilized lbs N	lbs P_2O_5
BROWN	1959	30,322	3,879	6.1	15.6	473,238	1,210,248	15.6	39.9
	1964	36,060	4,752	8.4	15.2	798,336	1,444,608	22.1	40.0
	1970	43,991	7,344	13.5	13.9	1,980,180	2,038,852	45.0	46.3
	1974	59,566	8,926	13.9	13.9	2,481,428	2,481,428	41.6	41.6
CALUMET	1959	13,080	1,689	6.1	15.6	206,058	526,968	15.7	40.2
	1964	20,313	2,820	8.4	15.2	473,760	857,280	23.3	42.2
	1970	30,367	4,585	13.5	13.9	1,237,950	1,274,630	40.7	41.9
	1974	45,092	6,901	13.9	13.9	1,918,478	1,918,478	42.5	42.5
OUTAGAMIE	1959	92,837	10,622	6.1	15.6	1,295,884	3,314,064	13.9	35.6
	1964	100,050	12,823	8.4	15.2	2,154,264	3,898,192	21.5	38.9
	1970	98,075	16,120	13.5	13.9	4,352,400	4,481,360	44.3	45.6
	1974	125,383	19,957	13.9	13.9	5,548,046	5,548,046	44.2	44.2
WINNEBAGO	1959	60,914	5,789	6.1	15.6	706,258	1,806,168	11.5	29.6
	1964	56,300	6,345	8.4	15.2	1,065,960	1,806,168	18.9	34.2
	1970	58,630	8,578	13.5	13.9	2,316,060	2,384,684	39.5	40.6
	1974	74,220	10,505	13.9	13.9	2,920,390	2,920,390	39.3	39.3

[1]Census of Agriculture, 1974

[2]Water Resources Management Workshop, 1976

Table 9: Average Phosphate Requirements in lbs per Acre for Land in a Corn-Oats-Hay Rotation

	CORRECTIVE			MAINTENANCE								
				Corn			Oats			Alfalfa		
YEAR	1967	1973	1977	1967	1973	1977	1967	1973	1977	1967	1973	1977
Brown	57	50	43	39	38	50	n.a.	n.a.	31	28	27	36
Calumet	61	55	40	39	39	56	n.a.	n.a.	32	35	31	45
Outagamie	58	49	41	39	38	48	n.a.	27	31	33	n.a.	34
Winnebago	86	44	33	38	37	42	n.a.	n.a.	26	29	23	25

Source: Department of Soil Science, University of Wisconsin, Madison management policy of each individual farmer. An example of a nutrient budget for corn, grown for grain or seed, is presented in Table 10. On the basis of the quantity harvested in each county it was possible, using the quantity of nutrients removed by the crop, to calculate the demand for nitrogen and phosphate. The supply of nutrients from commercial sources is also shown in this table. It would appear from these estimates that corn land was receiving 25-58% more phosphate and 42-52% less nitrogen than the crop demanded during the year.

Table 10: A Nutrient Budget for Corn Grown for Grain or Seed 1974

	Bushels Harvested	Nutrient lbs. N	Demand lbs. P_2O_5	Tons applied	Commercially supplied nutrients lbs. N	lbs. P_2O_5
BROWN	1,147,512	1,032,760	1,401,629	1,814	504,292	504,292
CALUMET	1,306,282	1,175,653	457,198	2,003	556,834	556,834
OUTAGAMIE	2,819,230	2,537,307	986,730	5,612	1,560,136	1,560,136
WINNEBAGO	2,441,770	2,197,593	854,619	4,573	1,271,294	1,271,294

Source: Census of Agriculture 1974

[1]Bushel requirements taken from Walsh (1972).

This imbalance is explainable. The nitrogen deficit must be coming from two principal sources: manure and microbial fixation. In each of these counties alfalfa is an integral part of a cropping rotation and this crop should be credited with supplying nitrogen. The animal component of a mixed crop-livestock system must also be credited with supplying a major portion of this deficit. Phosphorus, on the other hand, is shown to be in excess supply which reflects a county-wide trend in the building up of the soil's phosphorus status. This trend is questionable from an environmental viewpoint because nutrient concentrations are related to the fertility status of the soil. And it is also questionable from the farmer's perpective--it may not be an economic practice to over fertilize in any one year and more attention should be given to analyzing a field's fertility so that commercial fertilizers can be blended accordingly.

The increasing quantities of nitrogen and phosphorus being applied to the soil can only mean an increase in the amount of nutrients that could be potentially lost from agricultural land. Before pursuing the water quality implications of this trend, we should first pause and consider the situation from the perspective of the individual farming the land. It is reasonable, though not at all necessary, to assume that the farmer applies fertilizer with the view of maximizing some objective, or set of objectives. For example, the attainment of this goal may necessitate the application of 50% of the nitrogen consumed at the farm level, to get a 10% increase in yield--even if a major portion of this nutrient is leached into ground waters or carried away in surface runoff. Clearly, it is not sound management to over-fertilize and it is in the best interest of the individual to increase the efficiency with which nutrients are utilized by plants--much can be done by synchronizing the supply and demand relationships, better fertilizer placement and, in general, better management. Of course, many factors are outside the farmer's control, such as rainfall events; yet it still remains that the private individual is primarily concerned with weighing the private benefits and costs of fertilizer use. The quest for higher levels of agricultural production may simply be incompatible with the desire to minimize the environmental impact of higher fertilizer use.

Researchers have found that water flow is the most significant determinant of nutrient losses (Taylor et. al., 1971; Kilmer, et. al., 1971). The transport of nitrogen in the environment is an extremely complex process because of its vertical mobility in the soil system (free draining soils enhance this movement)--seepage losses may account for extremely high quantities of nitrogen while surface runoff losses are generally small except when heavy rainfall follows applications. In Illinois, the highest concentrations of nitrate occurred in grain producing areas with well-drained soils; these concentrations were usually highest in the spring and early summer period (Seatz, 1977). This particular study estimated that 88% of the nitrate nitrogen originated from the soil and inorganic chemical fertilizers; with 12% originating from other sources such as the atmosphere and animal wastes. Similar results were reported by Kohl et. al. (1971) who established that in times of high nitrates nitrogen concentrations 55-60% of the nitrogen found as nitrate originated from nitrogenous fertilizers. The evidence is therefore rather compelling that an increase in the use of nitrogenous fertilizers will increase the concentration of nitrates in surface and ground waters.

Phosphorus on the other hand is not at all mobile within the soil, it remains very close to the point of placement, and the amount of phosphate in solution in the soil water is small. This means that most of the phosphorus is removed from the soil system by crops and by its association with eroded soil particles. Although most phosphorus is lost through soil erosion, the soil sediment can be either a contributing source or an absorbing sink for phosphorus--the reason being that soil solids interact with the surface water until an equilibrium level of phosphorus is established.

With the above information in mind, we will now present some research findings on the effect of fertilizer use, crop type, slope, and the method of application on the losses of nitrogen and phosphorus to the environment. We do not present these findings to conclusively establish relationships nor do intend to use these literature values quantitatively at this stage, rather we present them with the objective of illustrating some of the factors which determine the quantities of nutrients derived from commercial sources that may enter a water system.

The first and most obvious issue relates to the level of fertilizer use. Annual losses of nitrogen and phosphorus in tile drainage water in clay soils in Ontario are listed in Table 11. In this six-year study the per acre application of 15 lbs. of nitrogen and 60 lbs. of phosphate to all crops plus an additional 98 lbs. of nitrogen on corn increased the export of nutrients above the non-fertilized control plots.

Table 11: The Annual Loss of Nitrogen and Phosphorus in Tile Drainage Water, Woodslee, Ontario

	Nitrogen (lbs./ac)		Phosphorus (lbs./ac)	
	Not Fertilized	Fertilized	Not Fertilized	Fertilized
Bluegrass sod	0.18	0.18	0.00	0.01
Continuous corn	5.08	10.61	0.16	0.18
Corn in rotation	4.10	10.20	0.08	0.13
Alfalfa (2nd. year)	4.30	5.00	0.06	0.16

Source: Webber and Elrick (1967)

The results of Timmons et. al. (1968), which are presented in Table 12, illustrate the importance of crop density in decreasing nutrient losses from crop land. Except for the plots of hay, 79-94% of the nitrogen lost in surface runoff was associated with particulate matter and the nitrogen loss increased as the density of the crop decreased. The same general trend was found for phosphorus losses, although the proportion of phosphorus in the

Table 12: Nutrient Export in Surface Runoff From Experimental Plots-Sediment and Water Fractions

CROP	Total Nitrogen lbs/ac/yr	%	Total Phosphorus lbs/ac/yr	%
Hay:				
sediment	0.0	0	0.0	0
water	3.1	100	0.20	100
total	3.1		0.20	
Oats:[1]				
sediment	4.6	87	0.03	75
water	0.7	13	0.01	25
total	5.3		0.04	
Corn:[2]				
sediment	3.8	79	0.03	34
water	1.0	21	0.06	66
total	4.8		0.09	
Corn:[3]				
sediment	11.5	94	0.09	60
water	0.7	6	0.06	40
total	12.2		0.15	
Fallow:				
sediment	56.1	94	0.38	90
water	3.4	6	0.04	10
total	59.5		0.42	

Source: Timmons, et. al. (1968)

[1] 16 lbs N/ac and 26 lbs P/ac

[2] 49 lbs N/ac and 25 lbs P/ac

[3] 100 lbs N/ac and 25 lbs P/ac

sediment was lower. These results illustrate the management opportunity that exists for reducing surface runoff through the amintenance of a dense crop cover.

Slope also has a marked effect on the nutrients exported in surface runoff, as illustrated in Table 13 using the results of Eck (1957). The nitrogen and available phosphorus exported is seen to increase dramatically as slope increases. Furthermore, a row crop is shown to lose more nutrients on a given slope than a cover crop such as oats.

The method by which fertilizers are incorporated into the soil also influences nutrient losses. Holt et. al. (1970) showed that fertilizer that was broadcast and then plowed under resulted in lower total phosphorus concentrations in surface runoff. These findings are listed in Table 14.

These studies illustrate that the proper use of fertilizer--that is recognizing the importance of timing, the method of application, and the maintenance of a dense cover on sloping lands--can result in a decrease in the nutrients which enter the streams and lakes of a region thereby dampening the rate of the eutrophication process.

Animal Concentrations:

Animal waste is the byproduct of an agricultural production process and refers to the production of manure and other wastes, such as bedding and washing wastes, which are associated with the maintenance and feeding of animals. In many instances these wastes are spread on farm land thereby enhancing the nutrient level and structure of the soil. However, in other situations, these wastes are not incorporated into the soil and they may be disposed of in a manner which greatly enhances the probabilities of their entering a water resources system. In any event, just as the input of fertilizers increases the nutrient export potential from agricultural land, so

Table 13: The Effect of Slope and Crop Type on Nutrient Export in Surface Runoff

CROP	Slope %	Nitrogen lbs/ac/yr	Available phosphorus lbs/ac/yr	N:P
Corn	3	16.0	0.42	38
Oats	3	7.2	0.18	40
Corn	8	18.7	0.46	40
Oats	8	6.8	0.21	32
Corn	20	37.4	1.70	22
Oats	20	33.8	1.50	22

Source: Eck (1957)

Table 14: The Effect of Fertilization Application Technique on Total Phosphorus in Runoff

METHOD OF APPLICATION	TOTAL PHOSPHORUS (mg/l)
No fertilizer	0.08
Broadcast and plowed under	0.09
Broadcast and disked in	0.16
Broadcast	0.30

Source: Holt et. al. (1970)

does the means by which animal wastes are disposed of. Manure management is an integral part of the mixed-crop-livestock system which characterizes so much of Wisconsin agriculture.

We have derived an estimate, based upon the 1974 Census of Agriculture, of the animal concentrations, by type, for the LFGB area. By assuming an average live weight for each animal class, it is possible to calculate the animal unit[1] (AU) concentration for the study area. The results are listed in Table 15, where the AU concentration is shown to be 149.8 per square mile. On the basis of the animal type and live weight, it was then possible to estimate the yearly production of nitrogen and phosphorus. At best, the numbers represented in Table 15 represent an upper bound on the nutrient potential that is emited into the environment--49.6 lbs. of nitrogen and 11.13 lbs. of phosphorus per acre of crop and pasture land: How much of this nutrient potential is transported to a receiving body of water depends upon many factors. We shall discuss some of these below.

Manure handling problems, particularly those associated with the dairy industry in Wisconsin, are met by spreading manure on frozen snow-covered ground. An appreciation for the predominance of this practice is obtained by observing in Table 16 the proportion of observed feeding operations which reported the frequent spreading of animal wastes. Clearly, the majority of the farming units visited in this survey were spreading frequently, the barnyard runoff was uncontrolled and there were few adequate stacking facilities. It appears then that few livestock operations have the capacity to carry manure over into periods when its nutrient potential can be tapped by growing crops. Furthermore, the potential runoff from these animal concentrations

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[1] 1 AU = 1,000 lbs. live weight

Table 15: Estimated Total Manure Nutrients for the Lower Fox Green Bay Area

ANIMAL TYPE	ANIMAL CONCENTRATION				MANURE NUTRIENTS PRODUCED FOR 1974			
	Average weight	Animal units	Livestock[1] numbers	Total AUs	Total nitrogen lbs/yr	Total nitrogen total	Total phosphorus lbs/yr	Total phosphorus total
Dairy cows	1200	1.20	46,160	55,392	180	8,308,800	38	1,754,080
Dairy hfrs	600	0.60	28,276	16,955	90	2,544,840	16	452,416
Beef cows	1000	1.00	2,710	2,710	124	336,040	40	108,400
Beef hfrs	600	0.60	3,486	2,091	74	257,964	24	83,664
Steers etc.	750	0.75	14,263	10,697	93	1,326,459	30	427,890
Hogs	175	0.175	16,141	2,824	28	451,948	9	145,269
Sheep	100	0.10	630	63	16	10,080	2.4	1,512
Hens	4	0.004	58,677	234	1	58,677	0.4	23,470
Broilers	2	0.002	8,944	18	0.8	7,155	0.2	1,788
Horses	1000	1.00	576	576	99	57,024	17	9,792
TOTAL				91,560[4]		13,358,987[2]		3,008,281[3]

[1]These numbers were derived from the 1974 Census of Agriculture

[2]This represents 49.46 lbs of nitrogen per acre of crop and pasture land

[3]This represents 11.13 lbs of phosphorus per acre of crop and pasture land

[4] 149.8 AU per square mile

Table 16: Domestic Animal Waste Management Practices for Each County in the Study Area

COUNTY	BROWN	CALUMET	OUTAGAMIE	WINNEBAGO
Number of observations	42	26	36	32
DISPOSAL METHOD:				
Frequent, barnyard uncontrolled	40	26	36	24
Frequent, barnyard controlled	1	0	0	3
Adequate winter cap. barnyard uncontrolled	0	0	0	2
Adequate winter cap. barnyard controlled	1	0	0	3
STORAGE METHOD:				
None	41	0	36	6
Unconfined	0	26	0	22
Manure pack in barn	0	0	0	1
Above ground liquid silo	1	0	0	0
Other	0	0	0	3

Source: Wisconsin Conservation Needs Inventory, 1977 is high. Therefore, the practice of frequent spreading, especially on impervious soils, along with poor barnyard control under conditions of intense Spring overland flow, greatly increases the probability of the pollutants entering nearby water courses.

A study in Vermont showed that 4-11% of the nitrogen and 4-10% of the phosphorus applied in the form of manure, at a rate of 10 tons per acre during the winter months, was carried off in surface runoff (Midgley and Dunklee, 1945). Nitrogen losses were shown to be influenced by the amount of volatilization that occurred before a rainfall event, while both nitrogen and phosphorus losses were dependent upon the slope of the field and the degree of imperviousness of the soil. Minshall et. al. have reported that up to 20% of the nitrogen and 13% of the phosphorus contained in the manure applied during the winter months on frozen ground may be lost when ground conditions were conducive to maximum Spring runoff (1970). It was found that summer applications of manure, incorporated into the soil, resulted in less nutrient runoff.

If we assume that the manure produced by animals in the study area over a four month period, during which the ground was frozen, was spread and that 10% of these nutrients were transported away by surface waters, then 333,974 lbs. of nitrogen and 75,207 lbs. of phosphorus would be exported from the rural area. This represents a large shock loading to the ecosystem (0.85 lbs. of nitrogen and 0.19 lbs. of phosphorus per acre). Note also that this is in addition to the nutrients originating from crop and pasture land.

The nature of the interdependencies that exist at the farm level, between crop response, animal production, and nutrient status was depicted in Figure 2. Here the nutrients required for crop production are shown to be supplied from either commercial (inorganic) sources and/or from organic manures. In this situation, as is typical for the majority of feeding operations in Wisconsin, the supply and demand aspects of the nutrient budget are not in harmony. That is the cropping period, which spans the months of May through October is not of sufficient duration to meet the constant supply of manure throughout the entire year. A waste management plan is therefore necessary if the nutrient potential of these animal byproducts is to be realized.

Manure is a valuable byproduct to the farmer; a ton of wet dairy cattle manure contains approximately 10 lbs. of nitrogen, 2 lbs. of phosphorus, and 8 lbs. of potassium. These nutrients, especially nitrogen and potassium, are contained in the liquid portion of the manure, thereby necessitating some form of conservation, if these elements are to be utilized. In addition to supplying nutrients, manure also improves soil structure and tilth, which in turn reduces surface runoff by increasing the rate of infiltration. Experiments in Wisconsin have shown that 15 tons of manure applied in the Spring increased corn yields by 49%, in addition to increasing the infiltration of water by as much as 24% when compared with non-manured areas (Walsh et. al., 1971).

It has been estimated that the fertilizing value of manure could be nearly doubled through improved handling and storage procedures. Approximately 75% of plant nutrients consumed by farm animals is voided, yet only 30-40% of the feed nutrients are returned to the soil as manure. The return of these nutrients should be based upon the fertility demands of crops, especially crops with high nitrogen and phosphorus requirements such as corn and small grains. In other words, farmers should be able to demonstrate that the amount applied, timing of applications, and methods of spreading and incorporating the manure agree with the concept of "best practice available" for protecting water quality (Massie et. al., 1975).

Therefore there does exist an incentive for the individual farmer to conserve manure. This can be achieved by reducing liquid losses during storage and losses at the time of application from volatilization and surface runoff. The recovery of nutrients by corn is higher when the manure is applied in the Fall, or Spring, followed by Spring plowing (Hensler et. al., 1971). The importance of the timing of application is illustrated in Figure 4, where it can be seen that the total nitrogen in runoff was increased by several orders of magnitude depending upon the Spring thaw, by spreading manure on frozen ground. Vegetative cover is also a controlling factor in determining runoff losses of nutrients from winter-applied fertilizer or manure. This is illustrated in Figure 5, where the losses from fallow ground are consistently lower for each nutrient analyzed.

It appears then that much can be done at the farm level to minimize the export of nutrients from animal wastes in a manner which is consistent with privately determined financial incentives. But whatever system is adhered to at the farm level, the potential for nutrients and microorganisms to impact water quality still exists. The proximity of small dairy and beef feeding operations to waterbodies exacerbates the situation still further, and housing facilities are commonly located along small streams which serve as a means for disposing of wastes. An indication of the spatial relation that exists between agriculture and the region's water resources can be obtained by referring to Table 3; here 32-57% of the miles of county shoreland use was related to agriculture. A recent survey of the four counties in the study area estimated that animal concentrations were located, on average, within 20-8,793 feet of a perennial stream and 1,107-1,906 feet of an intermittant stream--in many cases, high animal concentrations are close to streams (Conservation Needs Inventory, 1977).

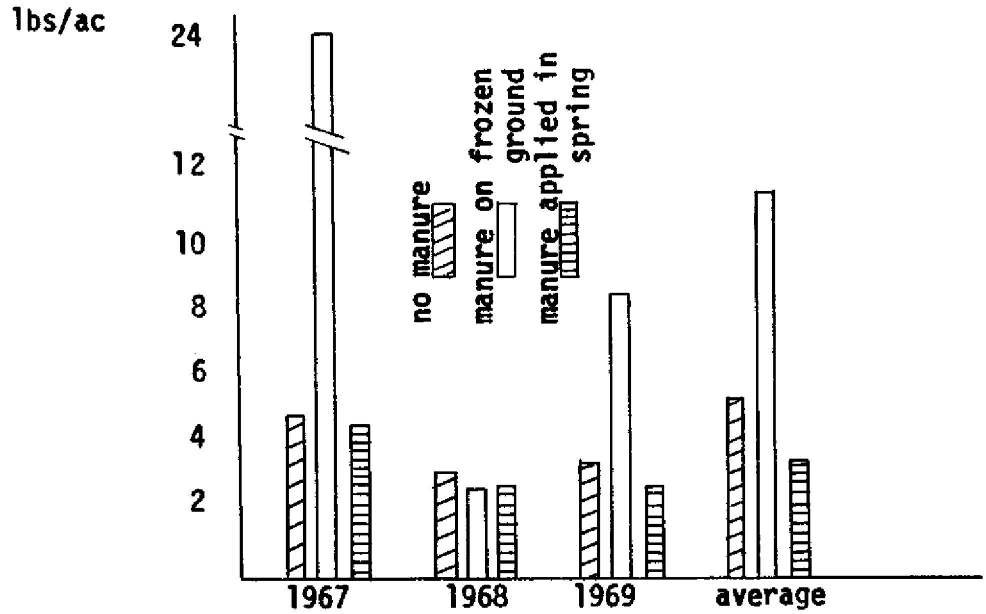

Figure 4: Annual Total Nitrogen in Runoff From Manure Applied to Rozetta Silt Loam (Minshall et. al. 1970)

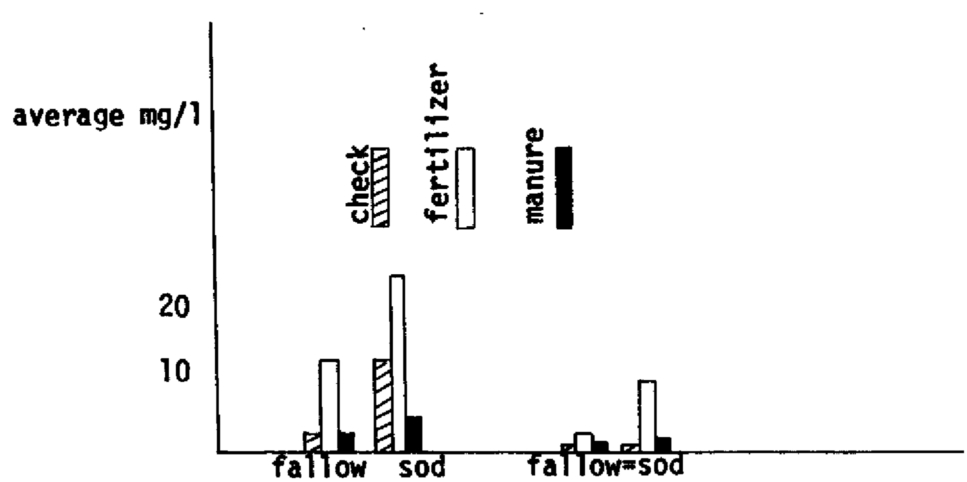

Figure 5: Average Concentrations of Nitrogen and Phosphorus in Winter and Spring Runoff From Fallow and Sod Areas Treated With Fertilizer and Dairy Manure (Powell, 1970)

In this section we have evaluated the potential role that animal manures can play in the eutrophication process of the LFGB region. The extent of water pollution caused by animal production is more dependent upon the management practices than upon the volume of wastes involved. Tha land offers a natural treatment facility for animal wastes and when they are applied judiciously these byproducts provide a valuable supply of nutrients for plant growth, in addition to improving the texture of the soil. Both of these phenomena represent monetary benefits accruing directly to the farmer. The fundamental problem rests with the design of manure management systems that better facilitate a correspondence between the supply and demand for nutrients. It is, therefore, a part of a larger managerial system which has varying demands upon labor and capital, and when viewed in this light an optimal manure management policy may not emerge at the farm level. Constraints of this nature must be identified so that policy can mitigate their effect in an attempt to induce environmentally conducive manure management systems.

Implications for the Region:

Current land use patterns in the region are inextricably linked with the level of water quality in the LFGB system. More than half of the land area is devoted to agriculture, a land use which has been shown to contribute significantly to the eutrophication of lakes and streams. Areal loadings have been calculated for different configurations of land use at the regional level and the export potential from rural land has been substantial in most cases.

These studies have served a purpose in that they establish possible implications which various land uses have for the export of nutrients. Farm land can contribute as much 2.4-24 lbs. of nitrogen and 0.92-3.88 lbs. of phosphorus per acre per year; feedlots can generate even higher loadings of these two key elements in the growth of aquatic plants. There is also a high potential for erosion from crop land--sediments also act as carriers of pollutants.

Land use patterns are important indicators of potential nutrient loadings. Once this has been established, however, more detailed analysis is necessary to determine the exact practices which initiate the process. That is, agricultural practices such as cultivation techniques, fertilizer use and manure management must be studied.

We have found that erosion is not a serious problem in the LFGB region--at least as far as average estimates go. The average rate of erosion calculated by extrapolating the recent Conservation Needs Inventory (CNI) estimates, ranges from 0.8 to 1.7 tons per acre per year. This is a gross estimate and if a sediment delivery ratio of 10% is assumed, the loading of sediment to the system is 49,377 tons, or 0.12 tons per acre per year. It would appear that the current level of soil erosion occurring at the field level is not significant. Yet, we are informed that turbidity levels are high--this means that more significant amounts are coming from areas of urban development, highway construction and streambank erosion. With 50% of the shoreland in the study area being directly associated with agriculture, we suspect at this stage that this may be a major source. Also, our analysis dealt with average field estimates--greater insights could be obtained from a distribution of contributing areas so that problem areas can be identified.

Mixed crop-livestock farming predominates in this region. As indicated above it consists of two interacting cropping and livestock subsystems. The interdependencies that exist between these parts are important to appreciate because the viability of an operation rests on the supply of high quality feeds for producing animals. Therefore, many farms are growing corn, oats and alfalfa, as major energy sources for milk and meat production. All of these crops respond to phosphorus, with corn and oats responding to nitrogen. The application of commercially supplied fertilizers has increased dramatically over the past 20 years and soil tests indicate that the phosphorus status of the soil is improving. This observation is important, since fertile streams are linked to a fertile hinterland.

The question that remains to be answered at this stage concerns the impact of current level of fertilizer usage. Again more detailed information is necessary, but a preliminary analysis indicates that too much phosphorus is being applied to cropping land. This is before any manures are returned to the soil.

We have illustrated, using experimental data, that fertilizing land does increase the export potential of nitrogen and phosphorus. Furthermore, slope, application techniques, the timing of application and vegetative cover all influence the nutrient content of surface runoff. Therefore, with the fertility status of soils increasing over time, other things being equal, this must inevitably lead to increased loadings. The next phase of our study will focus upon the impact of fertilizer management and how these practices moderate or exacerbate the nutrient influx from rural land.

Livestock numbers are high and they comprise the other major source of nutrients. Manure was shown to be a valuable source of both nitrogen and phosphorus; in addition, it improves the tilth of the soil, thereby lowering the infiltration rate. The constant supply of animal wastes coupled with the short lived demand for nutrients by crops, results in the need to either build up an inventory of manure when supply exceeds demand or spread the excess. Frequent spreading is a prevalent practice in the area and experimental evidence is conclusive that manure spread on frozen ground leads to extremely high losses of nitrogen and phosphorus in the spring.

We have estimated that domestic livestock produce 49.6 lbs. of nitrogen and 11.3 lbs. of phosphorus per acre of crop and pasture land per year. Not all of this is exported, and much is utilized by plants when incorporated into the soil, but if 1/4 of the total manure produced is spread during the winter months and 10% of the nutrient content is transported to streams and lakes, this will result in a loading rate of 0.85 lbs. of nitrogen and 0.19 lbs. of phosphorus per acre of crop and pasture land. This is, in addition to the nutrients emanating from commercial fertilizers.

To summarize, we feel at this stage that the export of sediment from rural land is not a major problem in the LFGB area. Nutrients, however, appear to have significant implications for water quality in the region--especially phosphorus, as this seems to be the limiting nutrient and it has been accumulating in the soil system over time.

IV. Research Implications

In this paper we have developed a framework to assist the reader to categorize the various sources of nutrient enrichment and then to provide a general appreciation for what each source contributes to current nutrient loadings. This framework was applied to the LFGB region utilizing existing data and from this preliminary analysis a number of research needs emerge. These are listed below in summary form.

1. More detailed information on land use is needed, especially cropping patterns. This also applies to livestock concentrations.

2. There exists the need to investigate the on-farm managerial decisions which lead to this configuration of land use and concentration of livestock. Here, research must focus on the practices at the farm level--that is, manure management, cultivation, fertilization, and so on. This is necessary information for evaluating water quality management options.

3. Regionally specific research on the overland transport of nutrients is necessary if the full impact of land use and animal waste management practices are to be appreciated. An analysis of alternative policies requires this information.

We shall be continually updating this report, incorporating data as it comes to hand, and hopefully some of the above needs can be satisfied. However, a continuing research effort which focuses upon these three aspects of land use requires more attention, so that the linkages between agricultural activity and water quality in the LFGB region are better understood and, furthermore, the design of management strategies can proceed on a sound technical basis.

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WATER USE IMPLICATIONS FOR THE BAY-H.J. DAY

Introduction

This paper has been prepared as a pre-conference report on past, present and possible future uses of Green Bay as a body of water. It is intended, along with other related papers, to stimulate thoughts and set the stage for an effective workshop during September 14, 15, and 16. It is not intended to be a comprehensive literature review of the subjects covered.

Significant uses (past, present and future) of Green Bay water may be categorized as:

1. Navigation - commercial and recreational
2. Water Supply - municipal, industrial, and agricultural
3. Recreation - swimming, boating, fishing, and hunting
4. Energy - cooling waters and sites for solar and wind energy facilities
5. Waste Assimilation - organic and inorganic
6. Commercial Fishing and Aquaculture
7. Mining

The paper has been organized to focus on each of these uses by posing two questions: (1) What do we know? and, (2) What more do we need to know? A summary table containing the author's opinion of research priorities is also presented.

Several comprehensive studies of Green Bay of special value to future investigators have been completed recently. Bertrand, Lang, and Ross reviewed relevant published research and explored possible alternative futures in a Sea Grant publication.(1)* The Great Lakes Basin Commission, in cooperation with its many federal and state participants, has published the Great Lakes Basin Framework Study which includes northwestern Lake Michigan as a study area.(2) The U.S. Water Resources Council has completed an assessment of the nation's water resources which includes the Green Bay area.(3)

Valuable new insight has also been gained through activities of local and regional organizations interested in Green Bay. Although largely unpublished at present, the water quality management studies of the Fox Valley Water

*See Selected Reference List on page 12

Quality Planning Agency, the Industry River Study Committee and the Wisconsin Department of Natural Resources are important. The Bay-Lake Regional Planning Commission and the Green Bay-Brown County Planning Commission are addressing important issues, e.g. the Bay as a source of potable water(4) and recreation.(5)

These publications along with many others have been important resources for use in preparing this review. They are the major sources of information used in answering the first question "What do we know?". Attempts to answer the second question "What more do we need to know?" have been more subjective and reflect the writer's bias based on the usual academic interest in new knowledge and on almost a decade of involvement in local water resource management.

BAY WATER USES - AN EVALUATION

Navigation

We know

- that most ocean going vessels are too large for the St. Lawrence Seaway
- that present and projected (to 2020) commercial shipping (tons) in the Bay is less than one percent of that on the Great Lakes(2)
- that coal and limestone shipments to Green Bay represent over 90 percent of the total tonnage at present(2)
- that increased shipping is dependent on new markets and/or new economic incentives
- that the energy cost per ton-mile for water borne shipping is the lowest of the five principal transportation modes(2)
- that new vessel designs, e.g. barge carriers and tug-barge combinations may change the present situation
- that water transportation is possible from Green Bay to Lake Winnebago through 17 locks of limited size (144 feet long and 35 feet wide) and depth (5.5 feet)(6)
- that only recreation boats have used the locks since 1952

We Do Not Know

- where in Green Bay (if at all) a copper/zinc ore reduction site and shipping port for recently discovered deposits in the Crandon area may be located
- the environmental and economic effect of an extended navigation season

- the environmental impact of increased shipping on the Fox River and lower Bay, such as the proposed Bay Port industrial facilities near the river's mouth

- the impact of higher petroleum costs on a shift from rail and truck to water borne shipping

- whether new vessel designs such as barge carriers or tug-barge combinations will prove to be technically and economically feasible for commercial shipping on the Great Lakes

Water Supply

We Know

- that most municipalities obtain drinking water from ground water sources (Green Bay, Marinette, and Escanaba are exceptions)

- that most industries use surface water from rivers, e.g. Fox, Oconto, Peshtigo, and Menominee, for manufacturing and return it in a degraded form to the river flowing into the Bay

- that ground water levels are steadily dropping in the Brown County urban area and that new water supply sources will probably be needed before 1990(4)

- that a Brown County metropolitan water authority utilizing Lake Michigan as an expanded water source has been recommended

- that Door County ground water is often polluted from malfunctioning holding and septic tanks

- that Fox River and lower Bay water quality has improved sharply in the past few years but still has limitations

- that toxic, e.g. PCB and arsenic, and nutrient, e.g. phosphorus and nitrogen, concentration levels in several basin rivers and the lower Bay exceed those of Lake Michigan

- that major economic and political hurdles must be overcome before the rest of urban Brown County could receive Lake Michigan water

- that agricultural use of surface and ground water for irrigation is insignificant

We Do Not Know

- the technical and economic feasibility of using surface water such as the Fox River as a supplement to existing ground water supplies

- the social, technical and economic feasibility of adopting a water conservation program to reduce the demand for potable water

- the social, technical and economic feasibility of using a dual water system (potable water distinct from water for other uses) in new urban areas to reduce the demand for potable water

- the future demand for irrigation water

<u>Recreation</u>

We Know

- that the demand for water oriented recreation (fishing, boating, swimming) in the Green Bay area is expected to increase from 60% to 200% between 1970 and 1990(7) depending upon the activity

- that the supply of boating facilities (marinas, ramps, parking spaces, rest rooms) is inadequate at present(7)

- that the number of species and total number of fish in Green Bay, particularly the lower Bay, has increased in the past three years

- that conflicts currently exist between users of various recreation forms in the Bay, e.g. water skiing and fishing

- that PCB levels in fish have caused the Wisconsin Department of Natural Resources to restrict commercial catches of carp and to suggest no more than one meal of local caught fish per week

- that fish caught in the lower Bay often have an unpleasant taste

- that new properly sized municipal waste water treatment plants are or will soon be operating at all major communities in the basin

- that swimming has recently increased drammatically in the lower Bay without public health agency approval

- that bottom sediments and algae will continue to deter some swimmers from using the lower Bay

- that turbidity will remain a problem in the lower Bay

- that the completed Interstate Highway 43 will reduce travel time from Milwaukee and Chicago to Green Bay by twenty minutes and increase water-based recreation demand

- that snowmobile and other winter recreation occurs extensively in many areas, and that the Bay, when frozen, has recently become a haven for snowmobilers

- that severe navigational problems due mainly to shallow water will continue to exist in the lower Bay

We Do Not Know

- the effect of cleaner river water on and the intensity of recreational use of the Bay

- the effect of Interstate 43 on recreational demand throughout the Bay area

- what other trace chemicals will provide future problems in the Bay ecosystem

- whether PCB's or pathogenic bacteria constitute public health problems for areas of Green Bay

- whether taste problems in fish will vanish

- the effect of a more restrictive energy policy on recreation on the Bay

- to what degree planned and organized multi use activities could increase the service capability of the recreational resources of the Bay

Energy

We Know

- that Wisconsin is an energy importing area and that the Federal energy policy or non-policy will have a major effect on the state

- that an increased tonnage of coal will be shipped on the Great Lakes in the future

- that solutions to the world energy problems are both complex and controversial and will depend on a number of technical, economic and socio-political changes over several decades(8,9)

- that waters of Green Bay and the Fox River are used for cooling purposes in the Pulliam Plant of the Wisconsin Public Service Corporation and that the impact of such use on the Bay has been thoroughly investigated(10)

- that other uses of energy associated with the waters of Green Bay, such as the location of wind-electric and solar heating facilities, could be developed

We Do Not Know

- the technical, economic or socio-political feasibility of different energy sources than those now associated with the waters of Green Bay

Waste Assimilation

We Know

- that Green Bay has been and continues to be the settling basin and downstream receiver of industrial, municipal and agricultural wastes and runoff from a highly urbanized area, containing a heavy concentration of pulp and paper mills, and a rich and extensive agricultural area

- that the lower Bay is highly eutrophic and that it receives major deposits of nutrient charged sediments each year from the Fox River

- that wind serves as the major driving force to mix the lower Bay waters and bottom deposits .

- that Fox River water flows generally along the east shore of the Bay before it mixes with Lake Michigan water

- that waste assimilation capacity of the Bay waters is less during winter ice conditions than during summer(11)

- that organic wastes from municipal and industrial upstream sources (point) have been reduced through treatment to approximately ten percent of the load released into the Fox River ten years ago

- that intermittent discharge of nutrient rich water from rural and urban sources (non-point) will become more apparent in the future as point source discharges diminish as a result of federal and state regulations

- that toxic chemical discharges from municipal and industrial sources will receive more attention in the near future

- that a recreation island created with dredge spoils will be built in the Bay a short distance downstream of a sewage treatment plant outfall where malfunctions could create public health problems

- that pulp mill producing 100 tons of pulp per day and discharging related organic wastes into the Oconto River ceased operation during 1977

We Do Not Know

- sufficient details of the Bay currents, as affected by wind and other boundary conditions, to predict the future location and concentration of chemicals or other trace materials released (accidentally or otherwise) into the River or Bay

- the effect of the Bay Beach recreation island on water currents including sewage effluent in the vicinity of Bay Beach

- the effect of a reduced sediment load from the Fox River on lower Bay waste assimilative capacity and associated algal growth

- the effect of river discharges and interaction with other hydrodynamic characteristics of the Bay on distribution of both dissolved and suspended materials in the Bay ecosystem

Commercial Fishing and Aquaculture

We Know

- that Green Bay waters are more productive than those of Lake Michigan

- that commercial fishing, which has diminished over the years, has the potential for returning(1), and that potential serious health problems associated with toxic PCB's have forced the state to alert the public to eat less fish from the Bay

- that PCB contamination is greater in some fish than in others

- that fish biologists do not agree on the proper series of actions to re-establish a healthy, well-balanced fishery in the Bay and in Lake Michigan

- that aquaculture (commercial growing and harvesting of aquatic plants and animals) has been economically successful elsewhere(12) and that it has been considered here(13)

We Do Not Know

- the proper action to quickly solve the PCB problem

- the biologically correct, economically sound, and politically acceptable solution to the Green Bay/Lake Michigan fishery management problem

- that aquaculture can be a successful business venture in Green Bay

- the degree to which commercial fishing will return and the impact of this increased activity on other uses of the Bay

Mining

We Know

- that iron and manganese nodules are deposited over a large portion of the Bay bottom north of Sturgeon Bay(1)

- that more extensive and valuable deposits have been discovered in the oceans

- that an extensive deposit of sand exists along the west shore of the bay

We Do Not Know

- the environmental and economic effects of mining on water quality and marine biota in the area

- answers to legal questions associated with possible environmental degradation linked to the mining

Summary

An attempt has been made to identify significant past, present and future uses for Green Bay waters with an emphasis on the future.

A table has been prepared to summarize the writer's opinions about these uses and their relative importance for continued research at this time. The table is presented in the hope that it will stimulate lively and constructive discussions during the September workshop. A few supporting comments may assist the reader in understanding why the selections were made.

Water supply, assimilative capacity, commercial fishing and aquaculture and energy were selected for the major future use category because those activities seem to be growing in significance. Recreation use will continue to be extensive but the projected growth will be tempered by energy costs. Shipping will increase but only to the extent possible under the limitations of port facilities on the Bay and the comparative isolation of the Bay from major commercial routes. Environmental constraints coupled with unpredictable market conditions will continue to make mining an infrequent activity.

Energy, assimilative capacity and commercial fishing and aquaculture have been assigned high priority research rankings since there are more unanswered questions relevant for potential Sea Grant interest and support in these uses than for the others; these are also, in my opinion, major uses for the Bay in the future. While water supply has also been predicted to be a major use in the future, it involves less research needs and more political and economic issues, than with the previously listed uses. Recreation and mining both received low rankings for research since there are, comparatively speaking, fewer unanswered questions in recreation and less societal need for mining.

WATER USE IMPLICATIONS FOR THE BAY

SUMMARY TABLE

Uses	Level of Use			Present Research Priority		
	Past	Present	Future	Phys. Life Sci.	Soc. Sci.	Overall Ranking
Navigation	major	minimum	moderate	1(high)	3(low)	medium
Water Supply	minimum	minimum	major	3	1	medium
Recreation	moderate	moderate	moderate	3	2	low
Energy	minimum	minimum	major	1	1	high
Assimilative Capacity	major	major	major	1	2	high
Commercial Fishing And Aquaculture	major	minimum	major	2	1	high
Mining	minimum	minimum	minimum	2	3	low

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OVERVIEW PAPERS

PRESENT STATUS OF THE GREEN BAY ECOSYSTEM-A.M. BEETON

Introduction

Green Bay is the major bay of Lake Michigan. It has long been important for commercial fishing, shipping, and for recreation. The northern part of Green Bay is connected to Lake Michigan and the great exchange of waters here makes this part of the Bay closely similar to Lake Michigan in physical, chemical, and biological characteristics. Big Bay de Noc at the northeast end is shallow, but it does not differ greatly from the north central part of Green Bay. Little Bay de Noc at the northwest end receives the inflow of several rivers, the major one being the Escanaba River, and as a consequence, this bay is much different from northern Green Bay. The southern half of Green Bay, south of Marinette, is shallow, with a maximum depth of 33m, but much of it is less than 9m deep. At the extreme southern end of the Bay is the mouth of the Fox River. This river is the major tributary to the Bay. It has a drainage basin of almost 17,000 sq. km and an average flow of 125 cu m/sec. The Fox River is considered to be seriously polluted. Along the lower 64km of the river is the largest concentration of pulp and paper industry in the world (Billings, 1966). Industrial and domestic wastes from a large population have resulted in gross pollution of the lower Fox River. At times little or no dissolved oxygen has been detectable in the lower river. No clean water biota and few pollution tolerant species live in this environment (Schraufragel et al., 1968).

The lower section of the Bay, south of Long Tail Point, is dominated by the inflowing Fox River water. North of Long Tail Point to Sturgeon Bay the Fox River water affects mainly the eastern half of the Bay where river water may account for as much as 80 percent of the northward flow along the east shore (Modlin and Beeton, 1970). (Fig. 1).

It has been suggested that a counter-clockwise current brings northern Bay water southward along the west shore. This water sweeps easterly near the Green Bay harbor entrance light where it mixes and flows northward with Fox River water. Mortimer (this volume) points out that this current regime has not been verified. The drift bottle studies made in 1971 (Howmiller and Beeton, 1971) do not show this counter-clockwise current. Nevertheless, the distribution of bottom sediments, biota, and the chemical characteristics of the water all indicate such a counter-clockwise current.

Sand bottoms with little organic material predominate along the western shore. Semi-fluid black-brown mud, similar to sewage plant sludge, occurs in the extreme lower Bay. It is highly organic, often with a hydrogen sulfide and sewage odor and contains numerous small fibers. Northeast of Long Tail Point and along most of the eastern shore a brown silt covers the bottom. Further north in the Bay a brown mud, which is more cohesive than the silt, occurs in the deeper waters. There muds usually have a light brown surface layer overlying the dark brown sediment, suggesting an oxidized layer overlying anaeorbic material. Despite this condition they do not have a hydrogen sulfide odor. Red clay is found in a few locations, some of which were former dumping areas for dredge spoil (Howmiller and Beeton, 1970).

Past Conditions

Green Bay has long been more productive than Lake Michigan and the southern Bay is similar in several aspects to two other highly productive areas of the Great Lakes, i.e. western Lake Erie and Saginaw Bay. It has a long history of pollution. One hundred years ago it was recognized that sawdust pollution of the Oconto River had interfered with spawning of the whitefish (Smiley, 1882).

Early surveys of the lower Fox River in 1925 and 1926 showed that this environment was so badly degraded as to make conditions "intolerable" for aquatic life (Wis. Bd. Health, 1927).

The investigations of Green Bay and the Fox River in 1938-39 (Wis. State Comm. Water Pollution, 1939) showed many of the conditions existed then which are of concern today. This survey had been undertaken because of obnoxious odors from the East River and reports of fish deaths along the eastern shore of the Bay under the ice. The lowest dissolved-oxygen conditions were present at the river mouth (3.2ppm) in the summer, but they occurred in deeper waters north of Long Tail Point along the east shore in winter (2.6-4.4ppm). Blooms of the blue-green alga <u>Aphanizomenon</u> were observed and although diatoms were important in spring, blue-greens dominated the phytoplankton in summer. It also appears that the mayfly, <u>Hexagenia</u>, was under stress since the nymphs, which usually live in burrows, would climb onto the gill nets. The commercial fishermen considered this behavior to be an indication of an impending fish kill. Apparently dissolved-oxygen concentrations were dropping to critical levels at the sediment/water interface. The pollution problems of the 1930's were attributed to waste sulphite liquor. The summer/winter differences were concluded to be the result of differences in the rate of biochemical oxygen demand of sulphite liquor waste at high and low temperatures.

The next survey by Surber and Cooley (1952) showed increases in pollution tolerant midges and oligochates and it was concluded that conditions had worsened during the intervening 13 years. A January 1955 survey (Balch, 1956) showed lower numbers of oligochaetes than found in the earlier surveys. For some reason, seasonal trends in abundance, with a mid-winter low, were not properly evaluated.

A comparison of benthos data taken at the same locations in 1938 and 1966 showed fewer oligochaetes and midges near the river mouth in 1966, but greater abundance of these animals 5 to 15km from the river mouth in 1966 (Howmiller and Beeton, 1967). Apparently conditions had deteriorated even for these pollution tolerant animals.

The studies undertaken through the Sea Grant Program in 1969-70 resulted in evaluation of the earlier studies and documentation of the changes in the benthic community of southern Green Bay (Howmiller and Beeton, 1971). Marked changes occurred in the benthic community between 1952 and 1969. Oligochaeta and Chironomidae, which have long been used in pollution surveys and as indicators of eutrophic conditions, increased in abundance. Leeches, snails, fingernail clams, amphipods, and Hexagenia decreased in abundance. These changes are similar to those observed in western Lake Erie (Carr and Hiltunen, 1965), except that snails and fingernail clams increased in Lake Erie offshore, but decreased near major sources of pollution. The disappearance of the mayfly, Hexagenia, was closely similar to what has been observed in western Lake Erie and Saginaw Bay (Schneider et al., 1969). Hexagenia had been very abundant and the 1939 report registered surprise at the few hymphs sampled, although they were present in 16 of 51 samples north of Long Tail Point. By 1952 Hexagenia were taken only at one station on the west side of the Bay. One nymph was taken in 1955 off the Oconto River. We did not find any Hexagenia in 1966 or 1969, nor were they in samples taken at 73 stations by the FWPCA in 1967 (Howmiller and Beeton, 1971).

A recent study of southern Green Bay was carried out from September 1973 to September 1974 (Patternson et al. 1975). Conditions apparently continued to worsen and dissolved oxygen dropped to zero over wide areas, but especially along the eastern shore in winter. The worst conditions in the river mouth continued to be in the summer.

A comparison of the 1938-39 (Wis. State Comm Water Poll., 1939) data with those of the above study indicate that some changes had occurred in the phytoplankton community by 1973-74. Abundance of Anabaena had increased from a maximum of 300 to 65,000 filaments/liter. Oscillatoria was not recorded as a major genus in 1938-39 but it was a dominant group in 1973-74. The abundance of Microcystis also apparently increased, although this is uncertain since they were included with "other blue-green" in 1973-74. Aphanizomenon concentrations were about the same in 1938-39 as in 1973-74. The maximum abundance of Melosira had increased from 210,000 to 615,000 frustules/liter. It appears that diatoms continued to remain important in the spring, but blue-green algae were more abundant and represented by more groups in the summer of 1974 than in the summer of 1939. It appears that similar counting techniques were used for both studies, but it is difficult to make detailed comparisons, especially since it appears that Table III-3 of the Patterson et al. (1975) report has an error, since Oscillatoria counts are given in frustules/liter.

Commercial fish production in Green Bay was around 15 million pounds annually during the 1950's, declined to around 7 million pounds in 1960-1965, then started to increase again in 1966 (Epstein et al., 1974). The 1977 production was 25.7 million pounds. These production figures reflect the greater productivity of Green Bay in comparison to Lake Michigan. The bay has produced about 50-60 percent of the total Lake Michigan catch, except during 1960-1965 (Epstein et al., 1974).

The total catch figures do not reflect the dramatic changes which have taken place in the fish community. Production in the early 1950's was dominated by the lake herring (Coregonus artedi), a native species, but by 1956 populations of this species started their precipitous decline. Lake herring populations underwent similar declines elsewhere in the Great Lakes. Production was up to 40 million pounds prior to 1925 and is now less than 1,000 pounds/year in Lake Erie. Similar declines occurred in Lake Ontario and Saginaw Bay, Lake Huron (Beeton, 1969). In 1957 the Green Bay commercial production was dominated by the smelt, which gained access to Lake Michigan in 1929. Other major species, in order of importance, comprising the commercial catch in 1956 were lake herring, carp, yellow perch, suckers, and walleye. Production of whitefish was only 9,000 pounds. This species had been important in earlier years, but its population had seriously declined, along with those of the lake trout, due to sea lamprey predation. The alewife was first starting to enter the commercial catch in 1957 and 46,000 pounds were reported taken from the Bay. This fish had only been reported to occur in Lake Michigan in the early 1950's. (See Fig. 2, 3, and 4).

The lake herring populations continued to decline and only 305,000 pounds were taken in 1977. Whitefish populations recovered, presumably due to control of the sea lamprey and 1977 production was over 1.8 million pounds. As the production of alewife increased to 26.9 million pounds in 1973 the catch of smelt declined to 790,000 pounds in 1977. The major species in order of importance in the 1977 catch were alewife, whitefish, smelt, yellow perch, carp, burbot, suckers, and bullheads.

The appearance of the burbot as an important species in the 1977 catch is another indicator of the success of the sea lamprey control program. This large predator was especially vulnerable to sea lamprey predation, as were the whitefish and lake trout. Over 235,000 pounds were taken in the Bay in 1977.

A number of other species also make up the commercial catch. These include chubs, northern pike, channel catfish, lake trout, sheepshead, white bass, menominee, bowfin, and buffalo fish. Production of these species has ranged from a few pounds to about 4,000 pounds in recent years.

Green Bay is divided into three fishery statistical districts (Smith et al., 1961). The northern State of Michigan waters comprise district MM-1. District WM-1 is southern Green Bay, bounded on the north by part of the Wisconsin-Michigan boundary from Menominee Harbor and then easterly to Egg Harbor. District WM-2 includes the Wisconsin waters north of Egg Harbor.

Most of the 1977 production was from District WM-1. Seventy-nine percent of the alewife, 99.1% of the perch, 99.9% of the carp, 71% of the burbot and 73.2% of the suckers were taken in southern Green Bay. The major production of whitefish (56.5%) and smelt (92%) was in District MM-1. Thus those species associated with colder waters are captured mostly in northern Green Bay, while the warmer water species are taken in the southern part. Major production of herring formerly occurred in the southern Bay, but they migrated into this area during the cooler months.

Chemical changes in Green Bay as far as total dissolved solids, chlorides, sulfate, and sodium have undoubtedly closely paralleled those documented for Lake Michigan (Beeton, 1969) because of the great exchange of lake and bay waters. Attempts have been made to document changes in macronutrients, but Rousar and Beeton (1973) concluded that any long term changes have been obscured by analytical differences, small numbers of samples, unrepresentative coverage, and conflicting results.

Present Conditions

The available data all suggest that changes have occurred in the southern Bay and that these changes are maintained by the deteriorated quality of the Fox River. The major impact of the River is on the extreme southern Bay south of Long Tail Point. This Point restricts exchange between river and bay water so that about 64 to 74 percent of the water in this area is river water (Modlin and Beeton, 1970) and measured transport ratios (total water volume to river water volume moving lakeward) are about 1.5. North of Long Tail Point to Oconto, Fox River water probably makes up about 15 percent of the volume and the transport ratio of about 6 indicates a greatly increased exchange between river and lake water in this part of the Bay. The transport ratios increase to 128 in the area between Sturgeon Bay and the tip of the Door Peninsula.

The chemical, benthic, sediment, and plankton data all indicate movement of Fox River water northward along the east shore. The influence of the river water is greatest in the southern Bay and gradually lessens northward.

The progressive changes in abundance and distribution of benthic animals as described earlier are most pronounced near the river mouth and along the eastern part of the Bay. The distribution of species of oligochaetes reflects the differences in environmental conditions (Howmiller and Beeton, 1970). Stylodrilus heringianus, a lumbriculid associated with the deep oilgotrophic waters of the Great Lakes and absent from Lake Erie, is common in the northern Bay, but not elsewhere. The most pollution tolerant tubificid, Limnodrilus hoffmeisteri dominates the fauna of the extreme southern end of the Bay. North of Long Tail Point two species of Peloscolex are important. P. ferox, a species associated with mesotrophic conditions, occurs in the western half of the southern Bay. P. multisetosus, which is associated with mesotrophic-eutrophic habitats, is common in the eastern half of the southern Bay. A number of other species were found to have similar distributions in the study by Howmiller and Beeton (1970).

The zooplankton communities differ considerably between the northern and southern areas of the Bay. The species composition and abundance of planktonic Crustacea in the northern Bay including Big Bay de Noc is almost identical to that of Lake Michigan, except that no Senecella calanoides and few Limnocalanus macrurus occur in the Bay (Gannon, 1972). The species composition of the planktonic crustacean community in Little Bay de Noc is closely similar to that of Lake Michigan but the abundance of animals is much greater than in northern Green Bay.

The southern Green Bay crustacean community is much different from that of the northern Bay and Lake Michigan. The major factor is the inflow of the

Fox River (Gannon, 1972). Apparently species which are common to Lake Winnebago are carried into the southern Bay. In the area influenced by the Fox River the fauna is more like that of Lake Winnebago than Lake Michigan. Species common to Lake Winnebago were most abundant or entirely confined to southeastern Green Bay. This area had much higher standing crops than the rest of the Bay and immature stages were found to be more abundant. Anoxia in the lower Fox River adversely effects movement of zooplankton from Lake Winnebago.

The planktonic crustacean fauna of the western half of the southern Bay consists mostly of species characteristic of northern Green Bay. Several species occurred in this zone in Gannon's (1972) study which were absent or rare in the eastern half of the southern Bay.

The distribution of planktonic diatoms also showed differences between northern and southern Green Bay, although the data did not indicate differences between the western and eastern parts of the southern Bay as did the benthos and zooplankton data. Holland and Claflin (1975) applied four multivariate methods in their analysis of diatom data resulting from a synoptic survey of Green Bay. Cluster analysis of the distribution of diatoms divided the Bay into a northern-western area, a southern-eastern area, and extreme southern Bay. Multiple discriminant analysis confirmed the definition of these areas. The northern-western area and the extreme southern area were relatively distinct whereas the southern-eastern area had properties intermediate to the other two. Major species of the northern-western area were Fragillaria crotonensis, Asterionella formosa, Tabellaria flocculosa and sev- species of Cyclotella. Total diatom concentration ranged from 325 to 1086 frustules/ml. These species were rare or absent in the extreme southern Bay where Stephanodiscus spp., Melosira ambigua, M. granulata, F. capucina, and C. meneghiniana were major species. Total diatom concentration ranged from 650 to 5349 frustules/ml at stations in this area. The southern and eastern Bay has a mixture of the major species from the other two areas and total diatom concentrations ranged from 21 to 832 frustules/ml.

Some elements of the extreme southern Bay flora occurred in Little Bay de Noc. M. ambigua was common at four stations. This distribution suggests a greater productivity of this bay.

The species found in the northern and western area are those found in Lake Michigan (Holland and Claflin, 1975). The major species of the extreme southern Bay are ones associated with eutrophic and/or polluted environments

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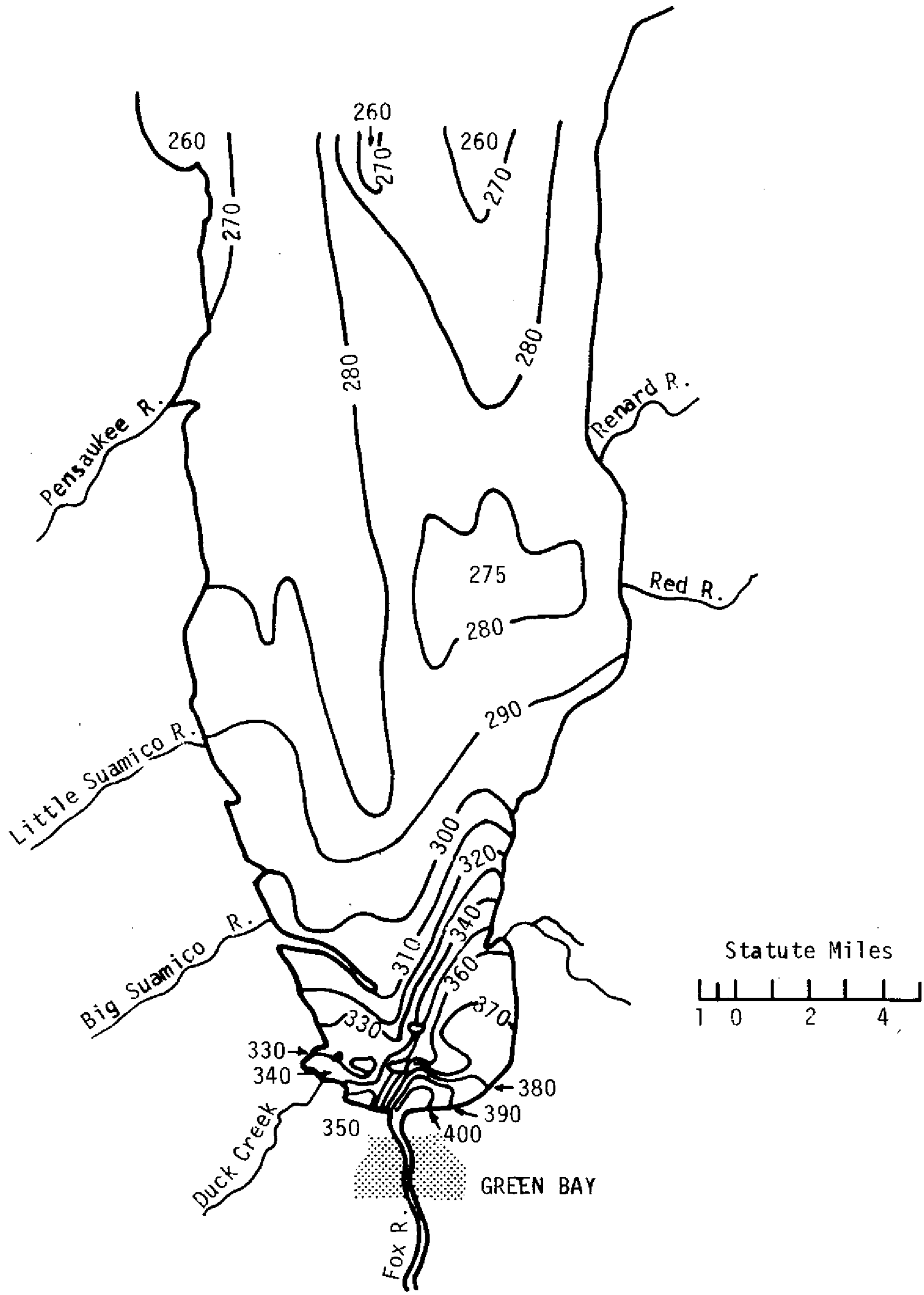

Figure 1. Distribution of Fox River Water as shown by conductivity in micro mho/cm at 25° C in southern Green Bay, July 22, 1968. (From Modlin and Beeton 1970).

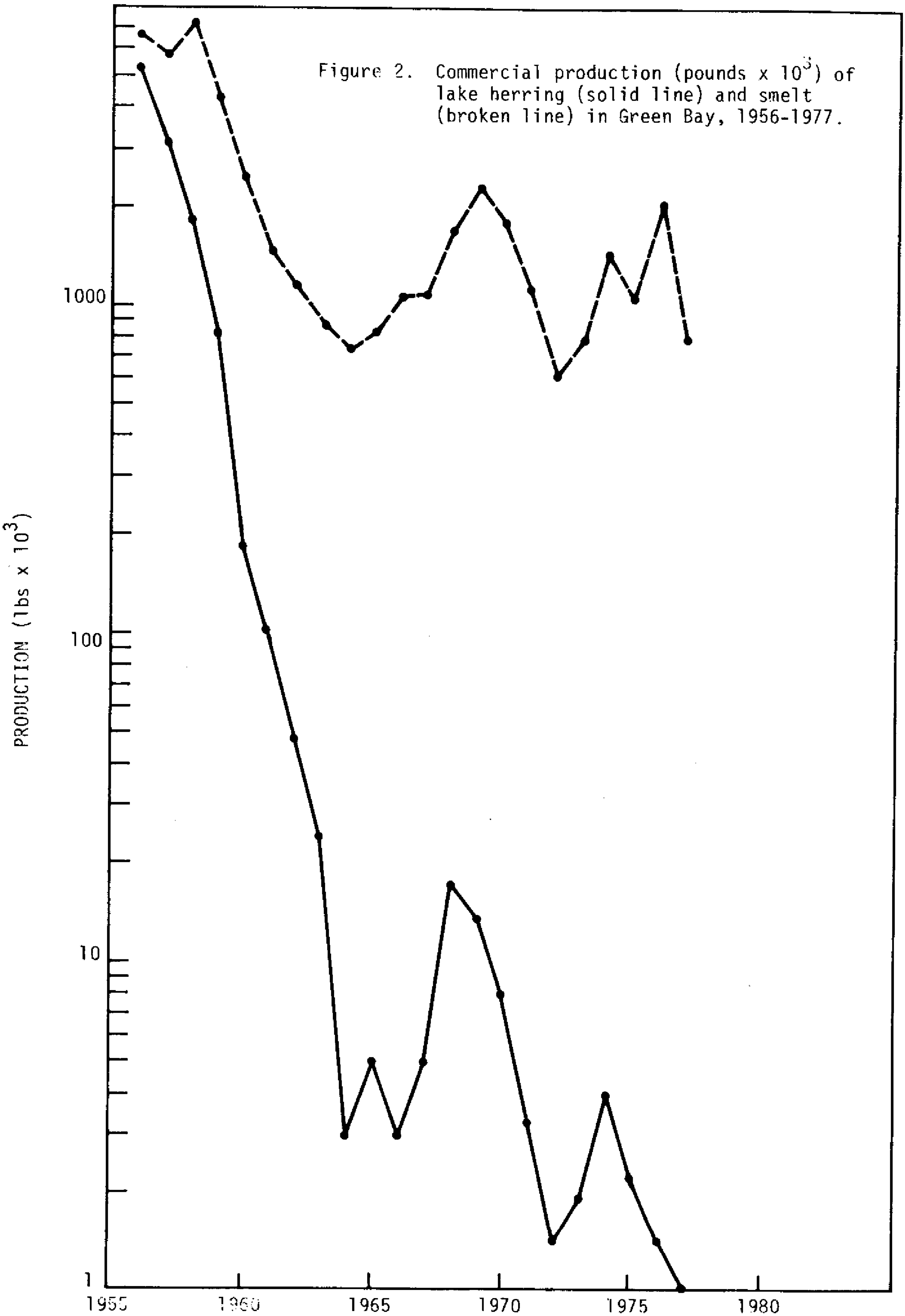

Figure 2. Commercial production (pounds x 10^3) of lake herring (solid line) and smelt (broken line) in Green Bay, 1956-1977.

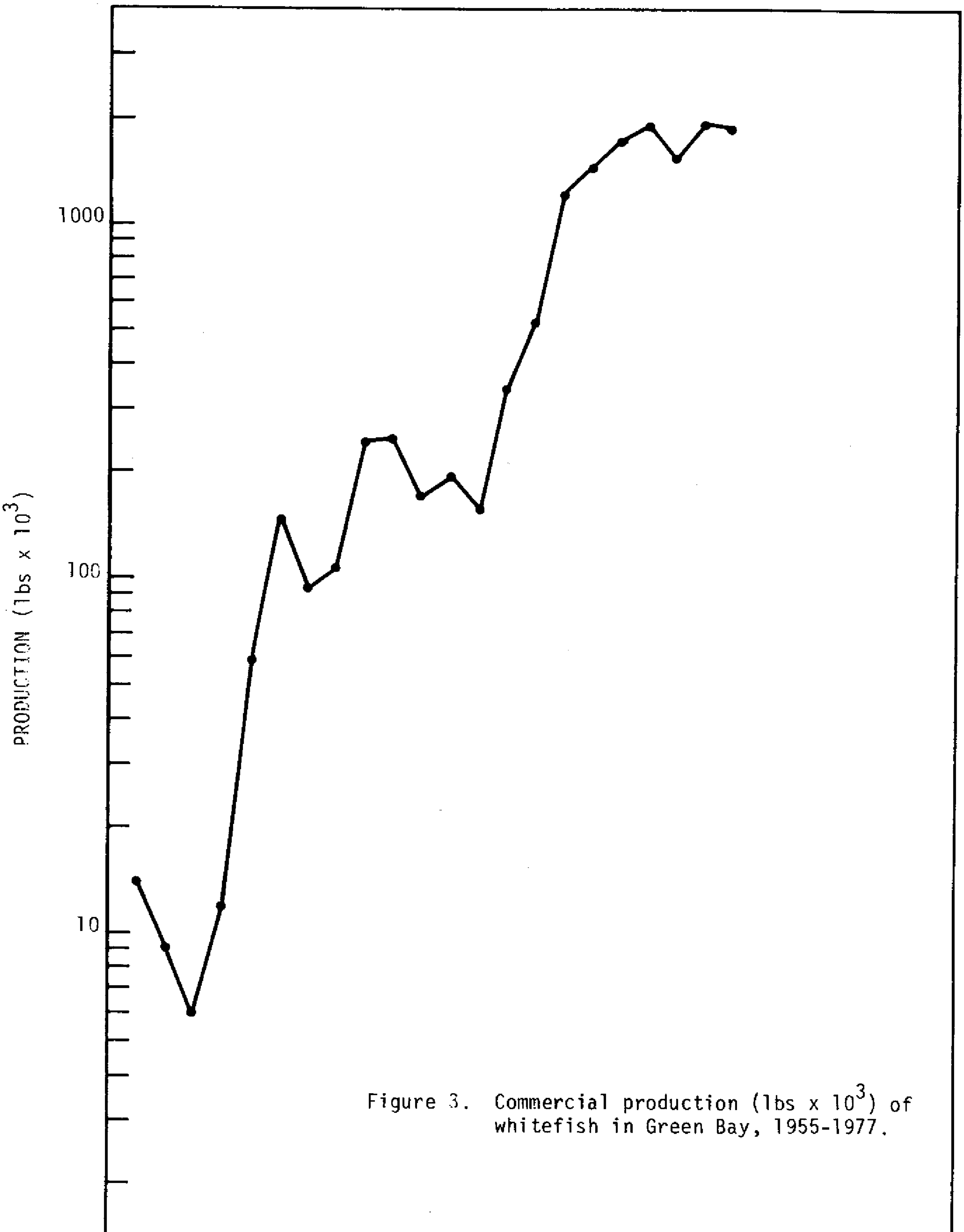

Figure 3. Commercial production (lbs x 10^3) of whitefish in Green Bay, 1955-1977.

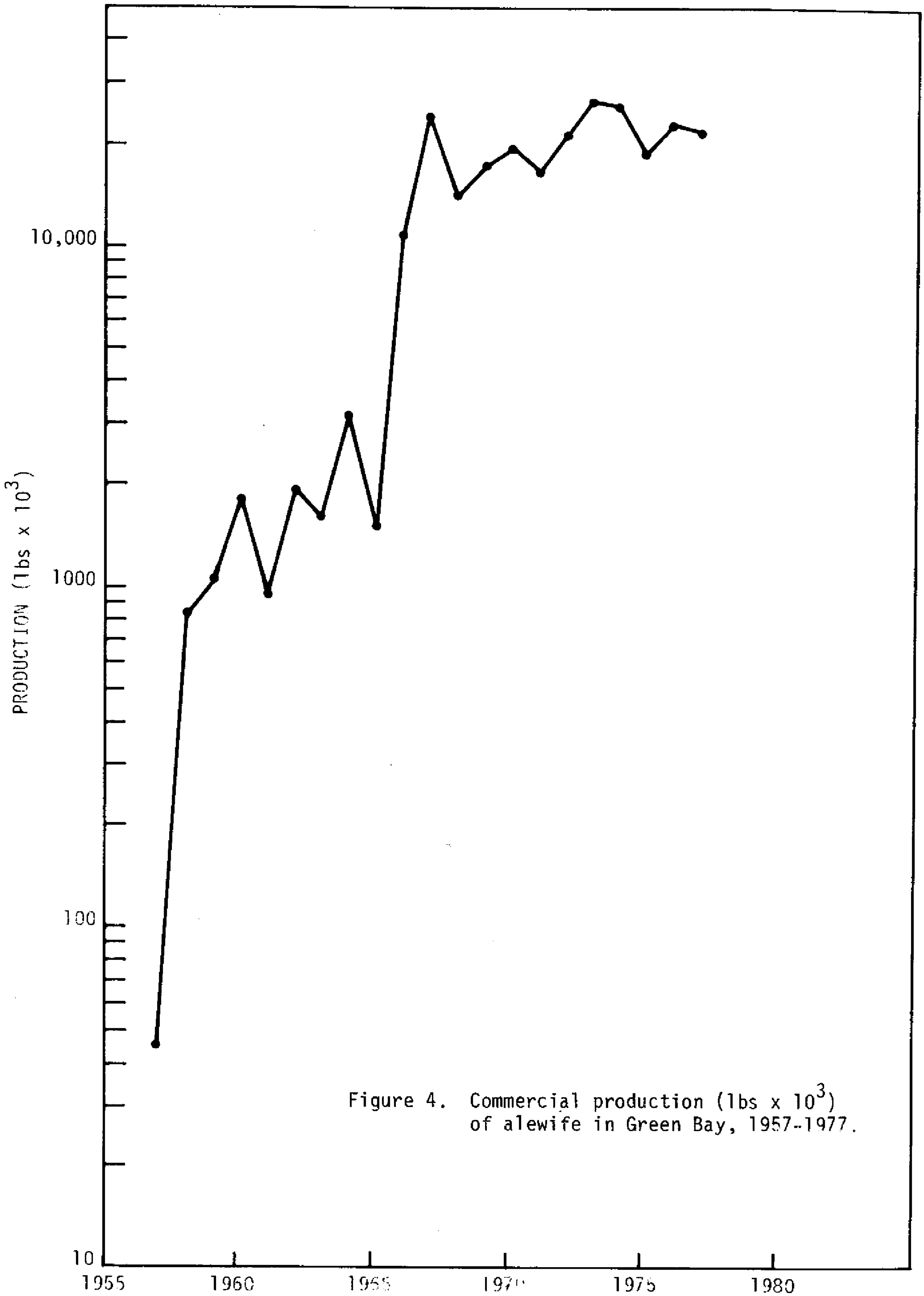

Figure 4. Commercial production (lbs x 10^3) of alewife in Green Bay, 1957-1977.

THE IMPACT OF RESOURCE DEVELOPMENT ON THE GREEN BAY ECOSYSTEM-JOHN E. ROSS

Green Bay and its drainage basin form a unique ecosystem. The ecosystem, while unique, is isolated neither in geography nor time, so one cannot take current status of the Bay or development of the region as given. This is an attempt to assess trends in larger setting that may impact the Bay. The analysis goes beyond the scope of an earlier Green Bay report in which I was involved (Bertrand, Lang, and Ross, 1976).

Let me start with two general conditions about the relationship between the region and the area beyond.

The first condition is that local environmental systems and local political jurisdictions are often dragged into the future by exterior conditions which have profound local consequences, but over which local individuals and governments have very little control and never will. The local area can try to respond to these exterior conditions and try to maintain a certain set of standards, but it has relatively little influence in changing the direction of events.

The second condition is that some major changes now gaining importance have their roots 20 to 30 years deep at least, and they will inevitably grow and spread through the next 20 to 30 years. In addition, the lead time required for making major adjustments appears to be increasing, rather than decreasing. To see what is happening, we therefore need to project ahead to the end of the century. Projecting is easier than predicting, because uncertainties are legion. Uncertainties exist in the quantity and quality of resources, in demographic trends, economic forces and their outcome, and in the possibilities of technological change. Many of the response situations are stochastic rather than deterministic, that is, there is a range of possible responses. The distribution of responses is broad and flat, rather than high and narrow. We could, therefore, be eminently reasonable, but quite wrong. In spite of that, the stakes are high, and so, at a minimum, we must speculate about the future. Within this landscape of speculation there do appear to be certain strong currents. But these currents may now be changing profoundly, that is morphologically, or structurally. Another way to say this is that we may be facing a series of non-linear change--in demand for resources, in the supply of resources, and in the state of the environment, and in the interrelationships of all three of these.

I intend to delineate what I think these currents are, and try to relate them somewhat to the Green Bay setting.

In the discussion I want to deal with the three countries of Canada, the United States, and Mexico, because in certain important resource issues we are bound together and will be moreso in the future. North America will be increasingly tied together in terms of resources and the general economy.

Population

The first of these currents is population.

The present population in the U.S. is around 225 million, in Canada 24 million, and in Mexico 62 million, for a total of 311 million. The current rate of population growth, according to official declarations is .8 percent in the U.S., 1.3 in Canada, and 3.5 percent in Mexico.

Those figures are based on births over deaths. Let's take those figures and project net population to the end of the century. We arrive at a figure of around 270 million in the U.S.; around 32 million in Canada; and 130 million in Mexico, for a total of 422 million in the three countries. That's an increase of around 36 percent in the next 22 years. Of course birth rates, or death rates, could change and the figure of 422 million could be perhaps 5 million on the high side.

There are around 1.2 to 1.3 million Mexicans entering the U.S. each year. The forces are such that at least some migration will continue. There is no practical policy that can change it to any extent. With the current rate of migration, by the end of the century, that will mean an additional increase of 24 million in the U.S. The total U.S. population would then be somewhere between 295 and 300 million. Currently our annual rate of increase in the U.S. is not .8 percent, rather 1.5 percent, and thus about half our current growth is due to migration (The Environmental Fund, 1977).

Initially there will be a disproportionate increase of population in those regions of the U.S. closest to the Mexican border, particularly California, but resource limitations and therefore employment opportunities, in those areas will tend to move these people into other regions of the U.S. and Canada. Over time they will spread further, particularly to regions of economic growth.

It is interesting that the per capita consumption of energy in Mexico has been, historically, about 10 percent of the per capita consumption of energy in the U.S. Per capita consumption of energy in Canada has been about 80 percent of that in the U.S. (Bryson and Ross, 1972). The consumption of resources by newly arrived Mexicans in the U.S. will not immediately rise to the higher level, but the pressure will exist to even out the distribution of resources within the U.S., and also among the U.S., Mexico, and Canada. Attempts at significant energy conservation among disadvantaged people in the continental economy will meet with angry opposition. It should also be noted that the new arrivals in the U.S. are not new births, that is, they are currently at the age to join the work force and the schools.

The point is that we cannot expect slackening of demand for resources, housing, and jobs because of a leveling off of population. Rather there is a multiplier effect of new population times high expectations.

Energy

The second major current is the changing array of energy resources. Considering all uses of energy our average annual increase has most recently been around 3 percent a year. As you know, this is a decline from rates of increase of a decade ago. The rate of increase has fluctuated some since the 1973 oil embargo and may settle in at around 2 percent. At the 3 percent figure we will double our current energy consumption by the end of the century. This means energy consumption is increasing about twice as fast as population and that, I think, will likely continue.

It is obvious that we are currently in the golden age of petroleum and natural gas. In the middle of this decade, the two fuels represented an incredible 74 percent of our consumption of energy (Shonka, et al., 1977). Natural gas has since declined as a proportion of the total mix. Petroleum is fluctuating around 45 percent. Coal has been at about 17% of the total, but is now increasing.

There is some consensus now that petroleum and natural gas will decline to 50 percent or less of the total by the end of the century in the United States. But the picture is different in Canada and Mexico because of the healthier status of their petroleum and gas reserves.

At the world level the optimistic and the pessimistic forecasters of petroleum reserves seem to be converging in their estimates of when production will peak, and that appears to be just after the turn of the century, a time period which is going to be rather interesting. From that time on the world will be on the back side of the petroleum production curve. It should be noted that production and prices of resources tend to fluctuate more widely as the supply diminishes and this may hold true for petroleum.

In my opinion the price of petroleum and natural gas will have shown some dramatic increases before the peak in production. The price of petroleum, now around $13 a barrel, could struggle upward with inflation until the mid 1980's. But in anticipation of a tightening supply, it is likely that a basis for pricing petroleum other than the market will emerge. That pricing policy will revolve around the replacement cost of petroleum, more specifically, what it would cost to produce gasoline or other liquid fuel from coal. The value of petro-chemicals will also figure much more strongly in the future of petroleum pricing. Formulas for discounting the future value of petroleum will be based on anticipated scarcity. Today, such a replacement cost would be around $25 a barrel for crude oil. This, I suggest, will emerge as the pricing policy of OPEC.

Mexico, not a member of OPEC, again surfaces as an interesting factor in regards to energy. Probable reserves of petroleum in Mexico have been put, until very recently, at 31 billion barrels. For comparison, the proved reserves in the U.S. are now around 35 billion barrels. The proved reserves in Saudi

Arabia are around 150 billion barrels; for the world, 654 billion.

Earlier this summer the Wall Street Journal estimated possible reserves in Mexico at around 120 billion barrels and street-corner speculation put the total at 160 billion (Wall Street Journal, August 30, 1978). You may have noted that President Portillo two weeks ago in his Senate of the Union address said Mexico's proved reserves were 37 billion barrels, but the possible reserves were a stunning 200 billion barrels. There are different definitions of reserves, and recovery technology differs drastically. I cannot support nor reject Portillo's prediction. Such a reserve in Mexico would extend the golden age of petroleum perhaps a decade or so, but we could not assume that the U.S. would capture the oil, at a price we designate, or that the Mexicans would pump it at our whim. There is increasing evidence that some petroleum producers are willing to hold production below demand.

The immediate reflex reaction is that Mexico's problems are solved. However, unemployment there ranges around 50 percent. Nation-wide, an estimated 800,000 additional jobs a year are required to avoid a rise in umemployment. The petroleum industry itself requires an investment of upwards of $200,000 per person employed. It might be more profitable for oil-wealthy Mexican elite to buy U.S. agricultural land and employ the surplus labor here than to keep all the petro-dollars at home, and such a policy also would ease unrest in Mexico.

In a slightly larger setting, it has been estimated that 70 percent of the world's remaining hydrocarbons (petroleum, natural gas, coal, oil shale, tar sands) lie in the three countries of Canada, the U.S., and Mexico. The danger in bonanza thinking in that regard is that some of those resources may require more energy to extract than energy produced, so that even a change in price would not stimulate their production.

I feel that in the United States petroleum and natural gas will decline steadily as a proportion of the total energy consumed and that we will turn to alternative energy sources to maintain or try to maintain rates of growth. An unresolved problem is that petroleum is a natural fluid lending itself to shipment in pipelines and supporting our existing highway transport network. There are formidable technological and economic issues in disengaging from petroleum in all sectors, particularly transportation, but including agriculture. I do not think that traditional economic theory concerning resource substitutability is ready for the shock wave that will be produced by the great petroleum shift. Russia, for example, is already showing unease in anticipation of that happening.

Let me look a little more closely, geographically, at the energy question. The first local item of note is that Wisconsin is a coastal state, bordered by water on three sides. And these are major bodies of water. These water systems provide transportation channels, but the water is itself a highly valuable resource, one that I think will increase in value ahead of general economic growth. The second item of note is that Wisconsin is not the reservoir of any hydrocarbons or uranium. We have tended to think of ourselves therefore as energy poor, even at the mercy of the energy resource owners. But that may be a major misunderstanding. A realignment of fuels, together with the water, could cause a different configuration to emerge.

One obvious question is the extent to which Wisconsin would produce electricity in the future. Because we have reservoirs of cold water, we may become the locus for generation of electricity that would be consumed beyond our borders, or the water could stimulate development here beyond our current anticipations. A decade ago the increase in electrical energy production stood at 6-7 percent a year, with a doubling rate of around a decade. Plans and action have dropped since then, at least in part because of the difficulties in implementing nuclear power, but also because of a softened consumer demand. The projected rate of increase in base load production now ranges from 2.7 percent per year to around 3.3 percent a year, depending on the utility.

Plans for base load construction indicate that the mix in the future would be 40 percent nuclear and 60 percent coal. The immediate outlook for nuclear depends on whether or not the plans for the units at Haven and at Tyrone do, in fact, go ahead. If for a series of complex reasons, these should get stalled or delayed, then we would expect that coal would be brought into the picture increasingly to at least maintain a 3 percent growth rate. In that case, I would not expect nuclear, at least with current technology, to regain momentum. Solutions to nuclear waste storage could change that picture. But uranium supplies are also finite and we are now selling at least some of our stocks to other countries, including Japan. This balance between coal and nuclear, assuming a doubling of production by the end of the century, is of obvious significance for the future condition of Green Bay. There are, of course, trade-offs between the two in environmental quality and pollution abatement procedures.

The question of coal and the Great Lakes was discussed in a seminar, in June, in Duluth, run by the Great Lakes Basin Commission (Great Lakes Communicator, August 1978). The report from the meeting said that projections of Great Lakes coal shipments in 1985 range from 6 to 77 million tons above the level of 37 million tons shipped in 1975. That is one of those wide ranging predictions, and more precision is needed if one is planning port facilities. A further conclusion was that coal movement by barge or laker, given the right conditions, can be less expensive than unit train. Presumably the coal would arrive in Duluth to be consumed through the lakes basin.

There is an involved argument about whether it would be more advantageous for the U.S. to mine Appalachian coal, prairie coal from Illinois and Iowa, or Western coal. All this argument is in terms of Btu's, sulphur content, strip mining recovery costs, and many other factors. If someone asked me today whether I thought Appalachian or mid-continent, or Western coal would predominate, I would likely answer <u>yes</u>. We will mine them all. We might, for example, find that though Western coal has proportionately less sulphur per ton, that we have to mine more of it to get equivalent Btu's and the total sulphur will come out about the same, I think there is a big lump of coal in our future and a pile of sulphur.

If one assumes a relatively rapid increase in population and a surging per capita demand for resources, and if one assumes a shift from petroleum and natural gas toward coal, then our estimates of growth in this region may well be on the conservative side. If Montana holds to its current attitudes, then the coal is more likely to be consumed or processed in this region than there (Bradley, 1978).

Water

But, let me direct our attention to another current that I think shows some basic changes in its morphology - the structure of water use.

Let's look for a minute at water, again in the macroscopic view. In the U.S. the average precipitation averages 30 inches per year. But 70 percent of this evaporates. The result is a net annual runoff of 8.6 inches. Since only about one quarter of this amount is currently being used in the U.S., it might seem adequate for the time being. Taking a national look at water, we could make a pessimistic projection. The projected daily demand of water at the end of the century is around 900 billion gallons (Greenwood and Edwards, 1973). If one were to assume no major change in technology (that is efficiency in water use); if one assumed a uniform supply from year to year; and if one assumes current rates of increase in per capita consumption, there would not be enough available water for the nation as a whole at the end of the century. In contrast, the Second National Water Assessment by the U.S. Water Resources Council is more optimistic (The Nation's Water Resources, 1978).

This, of course, oversimplifies. There will be technological changes. Annual rainfall does vary. And very important is the regional distribution. About 40 percent of the continguous U.S. receives about 72 percent of the rainfall. Washington and Oregon are resource wealthy regarding rainfall. The western plains have fought over the relatively limited supply for 200 years. Mexico looms as water poor, and Canada as water wealthy.

It is obvious that some river basins are being stretched beyond credibility. Perhaps the most incredible is the Colorado. I made two trips to that basin this summer, one to the southern reaches and one to the northern. The first was for a raft trip down the Grand Canyon. A marvelous wilderness, but I never forgot that we floated at the whim of the engineers. From day to day the flow is determined by the electrical demand from Phoenix, Las Vegas, and Los Angeles. The weekly newspaper in Page, Arizona wrote about angry hearings concerning plans for construction of 12 pump back hydro stations on the lower Colorado to re-feed the hungry turbines of Glen Canyon and Hoover Dams. In Phoenix, the legislature was arguing over a moratorium on further irrigation developments in Arizona.

Two months later in Aspen, Colorado, I read about the construction of a 570 million dollar diversion on the upper reaches of Hunter Creek, which will pump 17,000 acre feet across the mountains to Colorado Springs and, of course, out of the Colorado River Basin. The amount of water originally planned for diversion from Hunter Creek 10 years ago was 4,000 acre feet, but the amount now to be taken out is four times that, as a result of population growth in Colorado Springs and Pueblo. These are incidents, but they are indicative of the policy conflicts ahead for the river.

The people in the Southwest and in California may already be losing the taste of alkali dust in their throats from the recent drought. After all, the snow pack in the Rockies and the Sierras this past winter was immense. But woe unto them if they do. In this recent drought the West was within inches of a major disaster. We had some uneasy moments in the Midwest. If there is merit in the 22-year drought cycle, and there appears to be some, the next such cycle would appear in the mid-1990s. Will 24 million additional Mexicans live in a band from Houston to San Francisco then? And how many retired people will have moved from Green Bay?

There are, of course, ways to make water use more efficient.

Some writers have argued that 350,000 hectares of agricultural land will be under drip irrigation, worldwide, as early as 1989. Some agriculturists, using drip irrigation have reported increased efficiency in water use of from 40 to 60 percent (Shoji, 1977). This example is illustrative of an alternative technology. Even with that I feel that irrigation farming will over time give way to mining and urban water uses in the arid regions of the continent.

If one looks at the pattern of settlement in the U.S. over time, you note some very interesting characteristics. For the first two hundred years of European occupation of the continent, settlement tended to follow very closely the underbelly of the Great Lakes and along the rivers, leaping over the high plains to the far West. The traders and the bonanza hunters probed the hinterland but didn't stay. Finally, population in increasing volume began to spread out between the water courses. In more recent times we have developed great schemes to hold water, to move water, and in some regions to tap ground water so that we could live some distance from water. So now we have a situation where the location of population does not relate to the location of annual rainfall or the abundance of natural rivers. This was reinforced by an usually benign climate period in the first half of this century, one that may not be normal over a longer time period. So now we have a rapidly growing sun belt. But sun is the opposite of rain. We also have a rain belt. We have that vast supply of fresh, relatively clean water in the Great Lakes. And there are the great rivers of Canada, the Frazier, the McKenzie, and the St. Lawrence, running relatively unused to the Sea. I feel that by the end of the century there will be major new plans to move water, there will be some population limits imposed in water scarce areas and possibly major shifts in population.

Arable Land

We must deal with one more current. That is arable land. Here also, I see some potentially dramatic changes. In the United States we have about 470 million acres of arable land, 25 percent of the total. That proportion is one of the highest in the world and I think helps explain our general economic vitality. In 1976 about 81 percent of the U.S. arable land was under cultivation (Pimentel, 1976). An estimated 75 million additional acres are potentially arable, but then you are talking about wetlands and desert, and perhaps parking lots and green strips. It is clear that food production could not be increased significantly by mobilizing vast tracts of new arable land. The situation is tougher in Canada and Mexico, where the tundra and the Sonora will never look like Central Illinois, or like Brown County. To vastly stimulate agriculture in Mexico would take vast supplies of water, that will not come from the Colorado or Rio Grand Rivers.

Each year about 2.5 million acres of arable cropland in the U.S. are removed for highways, urbanization and other uses. So far a total of over 70 million acres have been converted to urban uses and highways. Strip mining has disturbed about 153,000 acres per year. The strip mine situation will change in the future. Large areas of primary wheat land overlie strippable coal beds in Montana, the Dakotas, Nebraska, eastern Kansas and north central Missouri. Illinois is one of the largest and oldest coal producing areas in the U.S. In 1971, it produced 59 million tons of coal, ranking fourth in national production. It leads the nation in reserves with an estimated 19 billion tons (Leonardo Scholars, 1975). Most Illinois coal is high in sulphur content and a lot of it lies under corn-soybean land. Clearly, some difficult choices lie ahead.

During the last 200 years, at least a third of the topsoil in U.S. cropland has been lost to erosion. Under normal agricultural conditions soil is formed at a rate of 1 inch in 100 years or about 1.5 tons of topsoil per acre per year. However, the average annual loss of topsoil is now estimated at 12 tons per acre. About 20 tons per acre are lost annually in continuous corn. The annual per acre reduction in yield due to topsoil loss is about a half bushel of corn. For the U.S. an estimated 200 million acres have now been either totally ruined for crop production by soil erosion or have been so severely damaged that the land is only marginally suitable for production.

To meet our own dietary needs in the U.S. we should be increasing food production at least 1.5 percent per year. To maintain our position as a major exporter might suggest 3 percent or more increase per year. That would mean doubling production by the end of the century. To double food production on current land resources however will require about a three-fold increase in energy for agriculture, and additional water. Recent yield increases in the U.S. appear due to three factors (1) abandoning land no longer productive (heavy erosion), (2) planting highly productive crop varieties, and (3) increasing production inputs by as much as 16-fold, (water, fertilizer, intensive planning). The Green Bay Revolution has been more intensive here, in fact, than in other parts of the world.

I simply do not feel that agricultural production of the kind we need can be drastically increased in the more arid regions of the country because of alternative competition for water. In fact, we are primarily concerned with the basic grains, wheat and corn, not with fruits and vegetables, and cotton. To achieve the production increases, we will need a more rapid intensification of agriculture in those areas of the country where water is relatively more available and this will likely increase the erosion problem. It is not impossible that we will join forces with Canada and Australia in some form of cartel arrangement for the international marketing of grain as the century comes to a close.

In the meantime the value of agricultural land in the Midwest has been increasing on the average from 12-16 percent a year, which means that it doubles in value in five years. While this rate of increase probably won't continue, it has set in motion a period of investment speculation in land that is and will continue to attract money from urban areas and abroad. Speculation tends to pick up a momentum of its own. One likely result is the application of intensive industrial type practices to food producing land, which would cause a shift in our land tenure patterns.

It would appear to me that intensive agriculture will gradually lose out to mining and to urbanization and industrialization in the Sun-belt area. This could give some breathing space for increased development there. But it is not out of the question that industry would take another look at development in the Southwest and reconsider the configuration of opportunities in the Great Lakes. Toward the end of the century we could see a surge of urban and industrial development in the Green Bay region because of resource limitations in other areas of the country, with the pivotal resource being water.

The Green Bay Region

It is possible that these currents of change would not have a major impact on this region, that is, beyond a conservative projection of what is now happening. In that case we would probably expect a 2 percent annual increase in production in agriculture and around a 3 percent annual increase in electrical production. This would mean doubling agriculture by about 2010 and doubling electrical production by the end of the century. Because this is a prosperous region of the country, I would expect population to increase slightly ahead of the national average and so there could be about twice as many people here within that first decade after the turn of the century.

There will be a major shift toward coal, with the possibility of growth in nuclear power. While this is not an overwhelming set of changes it is easy to forget that those rates of growth do add up significantly over the decades. One would expect that, under these conditions, nonpoint pollution from the drainage basin will increase faster than the increase in agricultural production. This is because the inputs in agriculture will have to increase at a faster rate than the outputs and because the intensified agriculture will increase erosion problems. A major program in soil conservation, one not now on the horizon, might change that situation.

Coal will cause a different set of problems than the ones to which we have become accustomed, including sulphur and its concomitant issues. We will talk more about acid rain, for example, in the future. Water quality problems will be more directly dependent on what we do in air quality. There will continue to be some complicated unexpected things like industrial chemicals, and heavy metals, and others that will cause concern and cost money to control. By the end of the century we will almost certainly know more about the relationships between chemicals and cancer and there will be much more public pressure on those issues.

All this would suggest that the economy of the region, while not isolated, would still be heavily determined by the local resources including forests, fisheries, arable land, scenery, and probably copper.

But the focus of my earlier discussion indicates that there might be a very different configuration emerging in the coming years. The realignment of resources could set in motion a series of changes which could turn this area into a major new industrial belt. For such a thing to happen the growth rates in energy would likely be an early indicator and would jump into the 7-10 percent category. A major increase in instability in the Middle East that would extend over a period of several years, would, I think, make such a development more likely, because it would almost surely hasten the rate of development of coal. Success in achieving the replacement cost as a price policy for petroleum could have a similar effect.

Some of the following might happen. We would go ahead with a system of transport canals that would link Chicago to the Mississippi River, Minneapolis to Duluth, and a year-round water link between Lake Superior and Huron or Michigan. Construction of electrical generating plants would accelerate in this region and would begin to occupy the Lake Superior shoreline as well as the Lake Michigan shoreline. The configuration of industry would change. Development would continue to be based primarily on regional resources, but would be more international in character. To do this would of course mean a fairly large increase in international trade via water channels. There would be major increases in population, beyond those generally projected, with the importation of a labor force. Agriculture and recreation would be forced to retreat at least to some extent.

With or without the rapid industrialization, it is possible that we will be considering schemes to move water from the Great Lakes to other regions of the country, to New York or toward the West. However, there will be major physical, economic, and political barriers to big schemes to move water. It seems unlikely that we would try to hydrolize the water in the lake for production of hydrogen fuel, but that is a possibility.

While it is not impossible, I think it unlikely that the region from Chicago to Marinette would become the equivalent of the Rhur Valley in Europe or of the Houston Harbor area. Such developments are the result of political action as well as a realignment of resource and environmental factors. What could very well happen, with the coming importance of coal, is a shift in the rates and kinds of growth beyond that we normally anticipate in our future's planning, thus, the non-linearities I spoke of earlier.

There is another major possibility for planned change--and this change is in the opposite direction of the two general scenarios I have described so far. John Steinhart, a geophysicist at the University in Madison, has published a very interesting little essay titled "A Low Energy Scenario for the United States: 1975-2050" (Steinhart, 1977). In it he projects a 64% reduction in per capita energy use by the year 2050 in the United States with no drastic change in the basic standard of living. To achieve this however would mean major changes in transportation, settlement patterns, and also a more subtle change in the way we view resources and energy. Our attention would shift in a physical way from emphasis on the relative cost of producing energy and resources more toward the efficiency with which we perform the work or produce goods. In such a concept, energy would not be cheap, as it appears to have been in the first 3/4 of this century. Rather resources would be valued according to their functions. This concept implies more than a trade-off between energy and labor. His analysis shows a proportionate decrease in the impact of pollution on the environment.

Steinhart may not have outlined the exact path to the future, but I do feel that thoughts like his will begin to emerge as we see the impact of one or more exponential doublings, both in the rate of consumption of non-renewable resources and the impact on environmental systems like Green Bay. Such schemes, for example might stretch out for generations the time span in which we burn Illinois coal. I can think of reasons why this would be advantageous, environmentally, economically and strategically.

Environmental Capacity

And what of the environment? It is obvious from my statement, that I feel we have not entered a kind of steady-state, economically, or that we have all the environmental problems in hand. Rather I think the possibility of instability will increase and that it will be more difficult and more complex in the future to maintain the standards now adopted or planned. We are, I feel, entering a period of increased resource exploitation.

I would like to suggest three very general environmental concepts that we should strive to define and then use as assessment techniques. These include (1) carrying capacity, (2) irreversibilities, and (3) natural environmental change.

Robert Heilbroner, in a fairly dismal book about the future titled An Inquiry Into the Human Prospect speaks of carrying capacity, thusly, "there is an absolute limit to the ability of the earth to support or tolerate the process of industrial activity" (Heilbroner, 1975). He suggests two aspects expressed in the words "support" and "tolerate." The first suggests some continuing productivity of both renewable and non-renewable resources. The second implies some capacity of the environment to absorb and recycle wastes. Unfortunately, carrying capacity, cannot be defined only in respect to some ideal capacity in the ecosystem. It quickly takes on economic values and even normative values. There is a price tag implied in every level of quality in the environment and there is also a tendency to try to place an economic value on the varying levels of quality. In addition the concept is loaded with aesthetic judgments. In other words, what quality of environment are we willing to tolerate? Nevertheless, the concept is useful in that it should be able to help predict what systemic changes will occur with what levels of development.

The key, of course, is the word systemic. We are just beginning to model and to understand environmental systems, which implies understanding direct and indirect impacts, feedbacks and non-linear responses. One must be able to integrate physics, chemistry, biology, and economics, perhaps even with human behavior, a most difficult assignment.

The second concept is irreversibilities. This implies that we could set in motion environmental change that would become irreversible at least in any meaningful sense to mankind. The burning of fossil fuels is an irreversibility. Nature will not recombine hydrogen and carbon in times short of eons. Loss of topsoil is probably also irreversible although the next major glaciation and its aftermath may replace it. There are, I think, two major kinds of irreversibilities that must be watched with some care. The first is a set of conditions that would vector in an irreversible way the major global systems such as the atmosphere, water, or global forest cover. One could imagine, for example, that if we succeeded in burning all the known coal in a relatively short time span that we might change the carbon dioxide balance enough to produce a major climatic change, reproducing one similar to 5000 years ago. The other kind of change is more local in scope but over a widespread enough area that it has a global environmental impact. For example, we could get in a situation where insects developed resistance to any credible chemical control while at the same time we destroy some of the natural control mechanisms. Or we could change soil conditions for bacteria, which might cause selective extinction, of the bacteria. We could probably change the eco-structure of Green Bay in some irreversible ways, both physical and biological.

The third concept is natural environmental change. We know that climate changes, apparently in short and long patterns, if not cycles. We also know that species and eco-systems change as does geographic form. Climate often seems to be the driving force in these changes but geologic processes and extra-terrestrial processes play a part. The point is that these natural processes set some outer limits for development in terms of moisture conditions, growing seasons, eco-tones, sea water levels, solar radiation, storm patterns, and many others. If we build a regional economy that pushes out to some of these outer limits then we can expect periodic trouble. Under any scheme for the future, planned or open-ended, we should at least know the margin of error we are willing to allow.

After all this, I would like to state that I remain an environmental optimist. I think we are capable of foolish mistakes, but there is another, more basic reason why I am an optimist.

For millenia we have been steadily gaining knowledge about how the environment works and how it may be manipulated. We have developed technology and created resources out of nature and it's all very exciting. But more recently we have begun to understand why the environment works the way it does, at the atomic level, at the cellular level, and at the eco-system level. From this, I think flows a growing respect for the amazing complexity of it all. We should also learn from this what we can and cannot manipulate without wrecking things.

While we should proceed with research that is inherently reductionist in nature, we should also proceed with a rigorous program of research that deals with the general phenomena that will never be conceptually tested in specialized research programs.

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EVENING ADDRESS

MAKING THE GREEN BAY CONNECTION FOR THE FUTURE OF THE GREAT LAKES-L. BOTTS

It is a pleasure and privilege to ponder research needs in Green Bay with such a distinguished group of scientists. I am indebted to a number of you for whatever knowledge and understanding I have of the scientific basis for the problems of Green Bay and the Great Lakes.

This evening I ask you to consider with me how the knowledge that you already have and the additional knowledge you may acquire as scientists can be used to make the necessary Green Bay connection for a better future for the Great Lakes system.

I will start by adding a third question to the two posed by H.J. Day in one of the pre-conference reports we were all asked to read before coming here. His first question was "What do we know?". His second question was "What more do we need to know?". My additional question is "How can we use what we already know to get on with cleaning up Green Bay now?".

What I am suggesting is that a researcher's understanding of a problem scientifically does not guarantee a solution in the real world. Demonstrably scientific understanding of eutrophication in university research centers has not lead to plans for action in the short run, which is the term in which most people operate in the real world.

The plea I make is that you as scientists consider not only what you would like to know to satisfy your own scientific "need to know" but what the users of Green Bay water, the sewage treatment operators and planners need to know to be persuaded that they not only have responsibility but can make a difference for Green Bay and Lake Michigan. I am questioning whether basic scientific research will be useful unless the people whose actions most directly affect the Bay also have access to the knowledge gained.

I will go even further and propose that research on Green Bay-Great Lakes problems is incomplete until and if the knowledge gained is, or can be, put to use in improving and protecting the quality of their waters and the integrity of their shorelands. In sum, I contend that your responsibility as scientists is not only to acquire knowledge for its own sake but to help the "doers" find out what they need to know. I ask you to consider how better connections can be made between scientists, planners, managers, and the doers on whom the future of Green Bay depends.

The question before this workshop is "What else do we need to know?". My question is "How can we use what we already know?". Let me use one of the task force subjects for this workshop as a case in point, Trophic Status. As I tell you why I ask this question, it will become obvious that the question is _my_ question as head of the Great Lakes Basin Commission, a regional planning agency. What I am really trying to do is to enlist your help in making more efficient and useful connections between the scientists who know and the doers who need to know.

I could start by talking about the various levels of responsibility for managing Green Bay water quality, including planning. Congress has discharged its responsibility by establishing a national policy that water pollution will be cleaned up and prevented in the future in the form of the Clean Water Act. The responsibility was to the American public which has demonstrated and confirmed its worry about water pollution.

The doers start with the U.S. Environmental Protection Agency, which must establish and carry out the program to implement the national policy, and the Department of Natural Resources, which must manage the State of Wisconsin's water pollution control program. The ultimate doers, on whom all the other levels depend, are the local agencies and individual dischargers of wastewater from diffuse or point sources around the Bay. The Great Lakes Basin Commission has coordinating responsibility for the eight-state watershed. The Great Lakes Basin Plan which we are formulating will use the areawide water quality management plans prepared by planning agencies, such as the Fox River Valley agency under Section 208 of the Clean Water Act.

In theory, these 208 plans are the means by which the national clean water objectives will be achieved at the local level. That is, the industries on the Fox River and the Bay, the sewage treatment operators in Appleton, Neenah, and the City of Green Bay, and the farmers in Brown County should be able to use the Fox River Valley 208 plan to find out how their actions will influence the trophic status of Green Bay in the short run and protect the trophic status of Lake Michigan in the long run.

Though there are legal sanctions that can be invoked under federal and state law, still, under our system of government, implementation of national policy depends on the willingness of local governments and individuals. When there is agreement on the goal to be achieved, as there is agreement on the need to clean up and protect Green Bay, then the willingness to take necessary actions depends on understanding of the problem and knowledge of how the local and individual actions will affect the problem. This is the connection that has not been made sufficiently for Green Bay and the connection that I believe you as scientists must help to make.

Ask yourself how many farmers know of any connection between spreading their manure on fields in January and February and the stinking algae in Green Bay in August. How many voters paying to pipe Lake Michigan water across Door County know that they must also pay to remove phosphorus in their sewage treatment plants? How many sewage treatment plant operators know why the phosphorus must be removed? The Fox Valley areawide water quality management plan does not tell them, and the planners who prepared the Fox Valley plan attribute the absence of usable recommendations to water quality "doers" to lack of scientific information.

According to this highly technical 208 report, there is insufficient data for mathematical modeling which the planners believe is essential to develop a management plan. Instead of being a blueprint for action, the Fox River Valley 208 plan is a plan to plan--when and if more scientific data are available.

My contention is that there is already enough information to allow translation and interpretation of what we know now about eutrophication in Green Bay to give guidance to local and individual action.

I am not contending that this is easy or simple. I propose that assisting the planners to apply scientific knowledge efficiently should be part of the challenge to the research scientists. We should get on with the job now, and provide new challenge to the scientists in monitoring, validating and improving methods as we go.

The need to make these connections is urgent. The phosphorus from Green Bay makes up about 20 percent of the total load to Lake Michigan. The role of phosphorus as the limiting nutrient for eutrophication of Lake Michigan has been established long since. The resources to support planning are limited and will not be renewed unless better results are obtained.

The importance of informing the farmers and the sewage treatment authorities how important their actions to control phosphorus are to the lake has recently been confirmed in a five-year, multi-million dollar research study. I refer to the massive international study by the Pollution from Land Use Activities Reference Group of the International Joint Commission, known as PLUARG.

Among the PLUARG findings reported this past July at the IJC's annual meeting in Windsor was that, generally speaking, few farmers in the Great Lakes Basin believe that what they do in their fields causes any pollution in the Great Lakes. Their skepticism is justified by the fact that the PLUARG study showed that, while runoff from agricultural lands can and does add to the phosphorus load of the Great Lakes, this connection is made only in some places. Green Bay is one of them, and further complication comes from the fact that the situation is different in the upper and lower parts of the Bay.

In lower Green Bay, which receives 1200 metric tons of phosphorus a year from all sources, 67 percent comes from point sources and 33 percent from diffuse sources, including agricultural lands. In the upper bay, 25 percent of the annual 200 metric ton load comes from point sources and the balance from nonpoint or diffuse sources. A good portion of the contribution in the lower Bay enters, of course, via the Fox River, which ranks second only to the Grand River in its tributary contribution to the lake's yearly phosphorus burden.

Besides showing that control of phosphorus from nonpoint sources is not necessary throughout the entire Great Lakes Basin, but could make a difference in certain areas including Green Bay, the PLUARG study also showed that it is not necessary to apply special controls on every farm and that different approaches may be needed from farm to farm. It is obvious why the need for information, education and technical assistance was emphasized in the PLUARG recommendations.

To now, I have been emphasizing the need for action at the local level, citing the deficiencies of the Fox River Valley 208 plan for Green Bay. This is not because this areawide water quality plan is unique in its failure to provide recommendations pertinent to the Great Lakes. Almost none of the 29 such plans nearing completion in the Great Lakes region deals with Great Lakes problems. The omission is not because the actions needed for the Great Lakes are prescribed through some other mechanism. On the contrary, both Douglas Costle, Administrator, and Tom Jorling, Assistant Administrator for Water and Hazardous Materials for the Environmental Protection Agency in Washington told Congress earlier this year that Great Lakes water quality problems are being solved through 208 planning.

The occasion for their comments was questioning by Great Lakes Congressmen in appropriation hearings of the EPA proposal to cut its own Great Lakes budget for 1979 to one-fifth the 1978 level. Congress did not agree and for 1979 EPA was directed to re-program several million dollars for the Great Lakes. Unfortunately, it is apparent that EPA policy-makers in Washington still do not understand the nature or importance of the water quality problems of the Great Lakes. Substantial cuts are now being proposed in the 1980 Great Lakes program funding.

One implication of the lack of appreciation for the lakes in Washington may be that, more than ever, their future depends on the actions of the people closest to them. I have tried to tell you tonight why those actions depend in part on the willingness of the research scientists who understand the problems to help local people plan for and decide on solutions. I hope that the need for better connection between the scientists, the planners, and actors in this workshop will start such waves that they may even be felt in Washington. Thank you.

TASK GROUP REPORTS

TASK GROUP NO. 1-TROPHIC INTERACTIONS

Dr. Paul Sager (discussion leader)
Mr. Marty Auer
Dr. Alfred Beeton
Dr. Arthur Brooks
Dr. Raymond Canale
Dr. James Kitchell
Mr. Jim Lubner
Mr. Bruce Markert
Dr. Jack Marshall
Mr. Daniel Olson
Dr. John Reed
Dr. Sumner Richman
Dr. Andrew Robertson
Dr. William Sloey
Dr. Forest Stearns

Objective - Investigations on Trophic Interactions

To understand the ecosystem(s) of Green Bay sufficiently well to allow reasonable prediction of responses to effects of a long-term nature, such as population change, energy utilization and economic developments, as well as those of a short-term nature including catastrophic events and management implementation.

Framework of the Recommended Study

We recommend a research program integrating the following components in a time period of sufficient duration to assure thorough understanding of this complex ecosystem:

A. Documentation of changes in Water Quality and Biota

B. Experimental Approaches to Food Chain Interactions

C. Modeling and Forecasting

In recommending this framework of research, we see a need for the program to be maximally sensitive to the changes in Green Bay emerging from the apparent improvement in water quality recently observed. It is important that the program include elements of study on areas where discrepancies or reversals in this improvement trend may appear (e.g., dredging, new toxics, fisheries problems, benthic changes, aquatic macrophytes, etc.). The program should also contain mechanisms for timely communication and interpretation of results and information generated so that the public is well aware of "What's happening to Green

Bay?". Elaboration of the three components follows:

A. Documentation of Changes in Water Quality and Biota

A well-coordinated, long-term research effort including descriptive, experimental and modeling components requires a central data base as a common ground for interpretation. This core of basic chemical and biological data is best collected through a standard monitoring program. Few university-based research programs can maintain the continuity required of an effective monitoring project. Accordingly, we recommend Sea Grant staff and/or other agency personnel be charged with the responsibility. The program should have two primary components: one, directed toward major tributaries as a measure of input patterns, the other distributed with the Bay.

Parameters monitored should include nutrient concentrations (phosphorus, in particular), measures of oxygen concentration, and B.O.D. The biological data collected for tributary streams and rivers might include those biota sensitive to improvements in water quality as well as estimates of biomass imported to the Bay (e.g., Lake Winnebago algae borne in Fox River waters).

Within the Bay, a series of broadly distributed reference stations should be monitored for those species assemblages of plankton, benthos and fishes indicative of seasonal dynamics and patterns of long-term variation and change.

Phosphorus and Other Nutrients

Though it is recognized that considerable emphasis has been placed on nutrient studies in the Bay, little progress has been made on understanding the full range of important processes that determine the actual levels of phosphorus in the water and the magnitude of the Bay's contribution to Lake Michigan. Processes of phosphorus transport and cycling within the Bay are poorly understood and though the exchange of phosphorus between water and bottom sediments is intuitively regarded as important, we presently have only inadequate measures of it.

Before reasonable predictions of phosphorus levels can be made, that is, in regard to alterations in loading, it is imperative that these internal processes (sedimentation, resuspension, sorption, diffusion, biological transport, advection and others) be assessed and quantified. At present, the technical capability for modeling phosphorus in Green Bay is at hand. Verification of the role of these above-named processes is necessary before further progress in modeling and prediction are possible. It is also important that we understand the degree to which Green Bay functions as a long-term nutrient sink and thereby buffers Lake Michigan from accelerated eutrophication.

The Importance of a Historical Perspective

Our contemporary perceptions of the Green Bay system are biased by a view clouded by cultural eutrophication. Recently-enacted water quality legislation has and will continue to effect gradual reversals of the eutrophication process. Effluent standards required of industrial and municipal point sources and the imminent phosphate controls for detergents will, in our view, contribute to the improvement in the quality of the water in the next decade. The trophic status of Green Bay will undergo some perceptible trends toward the conditions prevailing prior to the appearance of the first voyageurs in the basin. We know too little of those conditions and therefore, of the potential dimensions of the recovery process.

Although we should not expect complete recovery, we can and should be sensitive to the encouraging signs of progressive change. The review by Bertrand et al. and Beeton present some historic perspective but do not exhaust potential information sources. We recommend two additional efforts:

1. A thorough and complete review of <u>recent</u> research results and accounts of conditions in Green Bay should be compiled and summarized. Included with the initial scientific studies should be records and/or references of each fisheries yield plus the earliest of descriptions such as those included in reports of the original missionaries, fur traders and loggers, etc.

2. A paleolimnological reference should be established early in the research program. Cores taken at strategic locations will contain pollen, pigments, and fossil crustacea (cladocerans in particular) indicative of previous trophic status and interactions. As limnologists are usually among the last to arrive on the shores of a system already modified by anthropogenic effects, the fossil record preserved in sediments only a few centuries old may better guide our construct and interpretations of ongoing changes in the Green Bay system.

B. <u>Experimental Approaches to Food Chain Interactions</u>

Through numerous studies from the UW Sea Grant College Program and other state and federal agencies, many observations have been made on different features, though not all, of the Green Bay ecosystem(s). Research has been done on processes as well as components in this complex system. Though considerable insight has been gained from this research, the majority of it has been observational/descriptive in nature. The experimental approach can be particularly useful for studies on Green Bay as it would allow testing and substantiation of observations and descriptions made in previous or ongoing research. Physiological activities and reactions to stresses and stimuli of the sort evident in the Green Bay ecosystem need to be more accurately assessed at the organismal level. The experimental approach can provide an opportunity to gain the information required for more credible forecasting of important biological events in the changing ecosystem of Green Bay.

Enhancement of the trophic quality of the Green Bay ecosystem can best be accomplished through a fundamental understanding of the processes governing communities of organisms in the pelagial, benthic and littoral environments. Environmental alterations which stress the system may cause physical or nutritional changes which will affect the structure and pattern of the biotic community by altering phytoplankton-herbivore size distributions which in turn affect planktivorous fish dominance. Alternatively, environmental stresses may affect this predatory pattern leading to changes in the biotic community from the "top down", producing quite different food web patterns and shifts in the size distribution of the biotic components.

The Green Bay system provides an excellent opportunity to manipulate fish predator impact to study the effects of predatory processes in this biotic community as well as assess effects of food web interactions on year-class strength of important fish species. Factors controlling recruitment and distribution in the benthos are similarly important. Such studies will provide a conceptual and theoretical basis for testing the significance of "controlling factors" in characterizing the system's response to natural fluctuations and potential perturbations.

C. Modeling and Forecasting

It is important to develop mathematical models for trophic interactions and dynamics in Green Bay because they can be applied in several ways to significant problems. First, mathematical models can be used to help design limnological monitoring programs for the Bay. Second, activities associated with mathematical model development may help identify information gaps and specify future research priorities. Third, models can provide a common framework for interpretation of field and laboratory data. Finally, mathematical models (after careful verification) can be used to predict changes in water quality and trophic conditions in Green Bay which result from natural or man-induced disturbances such as modifications in land use patterns, nutrient loadings from municipaliies and industries, and stress caused by short-term catastrophic events. Models should be developed which can predict changes and response lag times in the level and structure of the plankton community, the concentration of dissolved oxygen, and the acceptable level of fish harvest in Green Bay. The mathematical models should be a computational framework which integrates biological and chemical interactions, external loading, and physical processes such as sediment resuspension, water circulation and turbulence, and photosynthetically available light.

TASK GROUP NO. 2-ENVIRONMENTAL CONTAMINANTS AND HUMAN HEALTH

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Dr. Marc Anderson
Dr. David Armstrong
Dr. Eric Christenson
Dr. Joseph Delfino
Dr. Alice Goldsby
Mr. Philip Keillor
Dr. Charles Remsen
Dr. Clifford Rice
Mr. Tom Sheffy
Mr. David Rockwell
Ms. Pam Snook
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INTRODUCTION

A research program on environmental contaminants should be designed to develop objective, well documented procedures that can be used to predict the pathways of potentially harmful chemicals in aquatic systems before extensive damage occurs or major investments are made in production facilities. Although either field or laboratory studies might provide the data necessary for environmental assessment, there are shortcomings in both. Field experiments are limited to those chemicals already present in the aquatic environment and are costly because of the large number of samples that must be collected and analyzed. Laboratory experiments, on the other hand, are relatively inexpensive and more easily controlled; but uncertainties exist in extrapolating these results to different environmental conditions. Both approaches are clearly needed. However, these must be closely coordinated to maximize information and minimize costs.

Recent legislation (i.e. Toxic Substances Control Act, TSCA, and Resource Recovery Control Act, RRCA) has given various government agencies the mandate to institute various preventative discharge measures as well as procedures for predicting the pathways of potentially dangerous chemicals in the environment. Various chemical testing and predictive protocols have been suggested. These efforts will undoubtedly change and it thus becomes important to provide a framework for assessing pollutant fates. A brief outline, which incorporates several TSCA concepts are presented below. The Task Group on Environmental Contaminants and Human Health visualizes these as important tools in coordinating the Sea Grant-Green Bay trace contaminant research efforts.

SOURCES/IDENTIFICATION

Research on chemical and biological contaminants in Green Bay requires an assessment of the sources of important contaminants to the Bay. This information is essential to insure that important contaminants are not overlooked and to develop strategies to eliminate contaminants found to cause problems in the Bay. A few of the most important sources in Green Bay are presented below.

PCB's

Although PCB's are currently known to be an important contaminant group in Green Bay and Lake Michigan, the sources are apparently diffuse and have not been quantified. For Green Bay, the Fox River is apparently an important source. However, the longevity of the PCB problem in Green Bay depends strongly on the extent to which the large bottom sediment PCB reservoir remains in the biological cycle (sediment ⟶ benthic organisms ⟶ fish). It is believed that the atmosphere does not serve as an important direct source to Green Bay because of a large watershed/Bay area ratio.

Paper Mills

A large number of chlorinated organic compounds are discharged into the Fox River as a result of chlorination of pulp and paper mill effluents. Approximately 100 such compounds have been identified in these effluents. However, for most of these compounds information in lacking on quantities and in-lake effects. In addition to chloro-organic compounds a wide range of chemical additives and by-products are also present in these effluents.

Arsenic

As a result of the disposal of arsenic-containing wastes along the Menominee River, the river is a major source of arsenic to the Bay. The loading is estimated to be about 45,000 kg. per year. Consequently, the possible biological effects of this high arsenic loading to the Bay is of major concern.

Petroleum Products

Approximately 900,000 tons of refined petroleum is shipped into Green Bay ports by tanker and tank barge each year. Furthermore, about 3,000 metric tons of petroleum per year enters the Bay in urban stormwater runoff and municipal wastewater. Petroleum is probably a major pollutant entering the Bay. However, information is lacking on the levels of petroleum accumulated or on the biological effects of petroleum in the Bay.

Municipal Waste Waters

Some industrial wastes are treated by the sewage treatment plants. Consequently, the sewage effluents may be an important source of contaminants.

Human and Animal Wastes

Disease producing bacteria, viruses, and protozoa enter the Bay in association with human and animal wastes. However, the distribution and persistence of these microorganisms in the Bay is poorly understood. These biological contaminants are of major concern in relation to anticipated increased recreational use of lower Green Bay.

Power Plants

Fly ash from the Pulliam Power Plant located near the mouth of the Fox River is collected by electrostatic precipitators and deposited in the nearby Bayport Industrial Site, formerly Atkinson's Marsh. The quantity of fly ash is estimated to be 100,000 tons per year. Consequently, drainage from the marsh into the Bay may be an important source of the more mobile elements such as boron, fluoride, arsenic, selenium, and sulfur.

Runoff from Agricultural Lands

Insecticides and herbicides used in orchards and other agricultural areas may enter the Bay through river discharge and direct runoff. Information should be obtained on the types and amounts of chemicals used in the drainage basin to determine whether these chemicals represent contaminants of potential importance to the Bay.

Information on major source functions for rather broad chemical categories will then permit a more detailed analysis of specific chemicals which warrant the study of necessary details involved in understanding their ultimate effects in Green Bay. It is recommended that the Sea Grant Program use present available data (from various agencies such as USDA, DNR, and Laboratory of Hygiene) and appoint a panel which would place priorities on specific chemicals (or classes of chemicals) and microbes based on the above considerations. Three guidelines should be followed in making such selections:

1. Amount produced.
2. Bioaccumulation potential.
3. Toxicity of the chemicals or action of the microbes on humans.

These criteria were chosen from some of the more important criteria which are presented in more detail below.

RESEARCH COMPONENTS

Once the list of chemical and biological contaminants have been determined, research on these materials should include the following parameters:

1. Continued evaluation and refinement of production and discharge data.

2. Development of improved analytical methods.

3. Determination of water solubility, octanol/water partition coefficients and other physical - chemical constants, e.g. vapor pressure, chemical dissociation constants, Henry's constants, etc.

4. Determination of photolytic degradation rates.

5. Determination of microbial degradation rates, preferably relative to standard reference compounds such as DDT.

6. Determination of adsorption characteristics.

7. Study of biological effects, e.g. LD-50 tests, Ames test, etc. Development of new procedures for testing effects should also be encouraged.

8. Study of bioaccumulation potential by laboratory and field testing.

The above list is largely an incorporation of those parameters considered by the Office of Toxic Substances as critical to identifying a priority pollutant.

RESEARCH FRAMEWORK

The objective, then is to incorporate the above physical, chemical and biological factors into the environmental framework presented below.

Physical Processes

Chemical measurements should be made in conjunction with physical measurements. That is, an understanding of water mass movement and suspended and bottom sediment dynamics in the Bay is essential. Many contaminants are associated with suspended sediments; hence, understanding the sediment transport will facilitate model development. It is important to realize that contaminants can be considered to have two cycles in nature. One would involve an abiotic cycle. That is, the contaminant is transported and transformed without passing through living components (except bacteria). The other involves contaminants that are cycled through the food chains. The latter is usually much smaller in terms of quantity. However, it is very important in terms of effects. The contaminant group strongly endorsed the efforts proposed by the Water Movement and Mass Transport task group.

Chemical Processes

A. Chemical analytical techniques used for the analysis of trace contaminants are expensive, time consuming, and often require sophisticated instruments for their performance. There is a need, therefore, to judiciously select, cautiously preserve, and carefully prepare these samples for analysis. As new contaminants are identified and new analytical techniques developed, we need to continually evaluate new and update old sampling, preservation and analytical techniques. In addition, interlaboratory calibrations should be used to assure quality control and greater utilization of these trace measurements.

B. Although much lip service has been given to the need for chemical speciation and elemental cycling, little actual research on these processes in the aquatic environment has been conducted. Because speciation and cycling affect the toxicity and availability of chemical components to biotic systems, these studies are urgently needed in order to interpret these effects. These speciation and cycling studies will necessarily involve both major and minor elements. They will also involve both biotic and abiotic systems.

Previously, elemental budgets have considered total elemental concentrations. These new studies should include the budget for the various elemental species. In addition, the inputs, outputs and sinks for these elemental species should be studied.

Speciation and cycling studies involve biogeochemical transformations. Measurements need to be made of redox potential, rates of methylation, rates of degradation, and the interconversions between particulate, biological and dissolved species. The role of chelation should be studied, particularly with respect to compound solubility. These studies should be conducted using sediments, pore fluids and water column samples and they must additionally include the vertical and horizontal distribution with time.

Biotic and Fate of Metabolites

Once information on the flow of chemicals is better understood it is possible to calculate dose rates, i.e., (concentration) X (flow) X (time). Modeling of uptake would then be possible. The panel recommends that it is oftentimes fruitful to use biological integrators for both short and long-term studies. These might include clams, birds, or certain non-migratory fishes. Cage studies are also valuable. In our effort to understand long-term trends of contaminant loadings, it is also worthwile to establish a biological specimen bank. All these data should facilitate the use of models. Finally, the task group recommends that any contaminant uptake model should be developed in close cooperation with biological models (for example, bioenergetic models).

Identified Problems

Containment or elimination of chemical, biological, or microbiological contaminants require carrying the information of contaminant effects to those having control over their introduction into the environment. Permitted levels of introduction, and procedures to cut down existing levels, need to be communicated to existing industrial and municipal agencies. Monitoring of contaminant response to control procedures needs to be done to assure that control procedures are adequate and that voluntary compliance is sufficient.

Exposure to Man and Biota

The effects of chemical contaminants on aquatic organisms and man are frequently related to the tendency for these contaminants to undergo bioaccumulation.

Consequently, research on bioaccumulation from bottom sediments and water through food chains is needed to understand and predict the exposure of contaminants to higher organisms, including man. Bioenergetic models should be considered as a tool for obtaining bioaccumulation information. Epidemiological studies are needed to evaluate the effects on man of exposure to contaminants such as PCB's through consumption of contaminated fish.

TASK GROUP NO. 3-WATER MOVEMENT AND MASS TRANSPORT

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Dr. Carl Bowser
Ms. Mary Castonia
Dr. Theodore Green III
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Dr. Joseph Moran
Dr. Vladmir Novotny
Dr. Robert Ragotzkie
Dr. D.B. Rao
Dr. James Saylor
Dr. Fred Spangler

Before turning to particular research strategies and to the means of implementing them, the task force identified three fundamental questions related to the hydrodynamicist's immediate objective of improving understanding of phenomena and mechanisms in Green Bay to a point at which useful contributions can be made to a parallel understanding of chemical and biological events and processes and at which management-related predictions can be generated with some confidence. The three interrelated questions were:

1. What are the pathways and fates of materials entering or formed in the Bay?

2. Which physical mechanisms critically influence biological production?

   (and more specifically)

3. Which mechanisms control dispersal and mixing?

The task force noted that transport, dispersal, and mixing were associated with two main classes of fluid flow: (a) more or less "organized" mean flows, which may be loosely referred to as advective; and (b) "disorganized" fluctuations (turbulence) superimposed on the mean flow. The task force also recognized that the mechanisms would have to be explored on a very wide range of scales of time and space (horizontal and vertical).

After reviewing examples, members of the task force were asked to prepare individual selections of not more than ten phenomena or mechanisms which demand further study, with particular reference to the Bay and to the above three fundamental questions, but leaving aside for the moment the selection of variables to be measured, methods to be employed, and priorities to be assigned.

The following list emerged:

Selected Phenomena and Mechanisms

1. Mean Circulation
2. Large Eddies and Gyres
3. Exchanges with Lake Michigan
4. River-Induced Circulations
5. Sediment/Water Interactions
    a. Re-Suspension (Surface Waves)
    b. Near-Bottom Currents
6. Thermocline Formation and Destruction
7. Circulation Under Ice
8. Atmospheric Forcing
    a. Trends, Extremes, Frequencies
    b. Air-Water Coupling
    c. Storm Surges
    d. Distribution and Variation of Wind Stress
    e. Extreme Events
9. Particular Circulations
    a. Langmuir
    b. Island Effects
    c. Stratified Flow
    d. Density Currents
    e. Vertical Circulations (Middle Bay)
10. Optical Properties
11. Materials Transfer and Transport
12. Ice Sheet Dynamics
13. Identification of Users

Having identified, in a general way, which mechanisms or phenomena urgently needed further investigation, the task force proceeded to consider how that should be done, i.e., which general categories of methods would be used. The following were identified as examples; and a list was also developed (not reproduced here) of variables to be measured.

General Categories of Methods

Truly synoptic (remote-sensing) surveys (aerial photography, satellite imagery, radar)

Quasi-synoptic surveys with several vessels and instruments (towed or fixed)

Regular cruises with one or more vessels, visiting a pre-designed network of stations

Continuous shuttle to-and-fro across a selected section or sections with towed depth-undulating instruments

Recording (or sampling) instruments at fixed stations, e.g., current meters, thermistor chains, profilers (O_2, ^oC, etc.), time-lapse cameras

Drifting instruments, e.g., "talking drogues", free profilers

Improved mixing-box models, using results from above methods (particularly quasi-synoptic) and taking variations in river flow and river water properties into account

Discretized simulation models, single and multi-layer, tested by results from some or all of the above methods

Water-mass tracers (natural, contaminants, or introduced) to test and verify models (e.g., isotopes, dye tracers, optical properties, chemical and biological tracers)

Laboratory experiments (e.g., wind-exposed basins, rotating or not)

New instruments

Having completed the foregoing preparatory stages, the task force prepared individual lists of ten more specific research projects, which (in the opinion of the preparer) urgently needed to be undertaken in Green Bay. In each list, the projects were ordered according to an "urgency rating scale" of 1 to 10 (with 10 highest). The lists, which showed a remarkable and encouraging degree of convergence, were then collated to form the final list which follows and which constitutes the backbone of this report.

<u>Selected Projects and Their Individual Ratings</u>

1.	Mean Circulations, Large Eddies and Gyres, Chemical Tracing	7,10,3,6,10,4,5,9
2.	Sedimentation and Re-Suspension (Bottom Current, Sediment/ Water Interactions)	5,4,8,3,9,3,8,6,10
3.	Green Bay Expedition Year (Seasonal Changes in Physics, Chemistry, Biology, Oxygen Distribution, etc.)	10,6,5,9,8,7,6
4.	Circulations Under Ice (Density Currents, Seiche Currents)	3,4,6,1,2,2,3,8
5.	Air/Water Energy Exchange (Wind Stress Distribution)	7,4,4,2,1,2,7
6.	Exchanges With Lake Michigan	9,7,1,7,10,9
7.	Thermocline Formation and Stratified Shear Flows	6,3,9,8
8.	Storm Surges (Extreme Events, Climatological Trends)	5,2,3,4
9.	River-Induced Circulations	2,5,7
10.	Remote Sensing (Satellite and Air Photography)	2,10,7

11.	Repeated Transect Cruises, Description of Upwelling/Downwelling Events and Long Internal Waves, Vertical Circulations	9,4
12.	High Resolution Current Meter and Drogue Networks to Resolve Relevant Circulation Scales (Model Verification)	8,5
13.	Identification of Users	4,5
14.	Langmuir Circulation	1
15.	Ice Sheet Dynamics	2
16.	Optical Properties	1
17.	Temperature Distribution and Climatology	10
18.	Toxic Substance Distribution as an Indicator of Mean Circulation	6
19.	Island Effects	1
20.	Roughness Under Ice	6
21.	Mass Transfer Between Lower and Middle Bay	3

TASK GROUP NO. 4-INFLUENCES OF LAND USE ON THE BAY

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Introduction

The task group agreed upon 12 research areas which can be considered important ingredients to enhancing our understanding of the ways in which land use activities have water quality implications for the Bay. These twelve are described below.

1. In-Lake Phenomena

If on-land emission runoff sources of nutrients and toxics are identified, can we be certain that their elimination will bring a noticeable response in water quality in the Bay? We are convinced that pollutants already in bottom sediments would confound the management and policy problems if a great deal of time and effort were spent to regulate on-land emissions only to discover that the Bay did not "respond" as people had come to expect.

2. Toxics and the Sources

There is some belief that toxics pose a much more serious threat than do nutrients and that perhaps too much attention is being paid to trophic status of the Bay vis-a-vis toxics. It is important to identify toxics. It is important to identify sources of toxics and the transport mechanisms whereby they move from origin to destination (the Bay).

3. Air Emissions

As more research identifies the significance of air emissions it becomes vital to understand the contribution of this source to over-the-land runoff of pollutants. In this case, the land is merely an intermediate step in the transport process. More effort should be undertaken to determine air-borne contributions to the water surface as well as to the Bay via land.

4. Hydrologically Active Areas

The contribution of pollutants to the Bay can be better understood by identifying those sub-units of the watershed which are extraordinarily active in a hydrological sense. This would include areas along stream banks where cattle congregate, farms located on particularly shallow and or pervious soils, and the like. An effort should be expended to locate the most active areas, and to document the movement of pollutants from these areas into the Bay.

5. Surface Transport Systems

One of the weak links in the relationship between a particular land use (and its attendant yield of nutrients) and ultimate deposition in the receiving water body is the surface transport system. There is a need for research on this component of the system.

6. Groundwater Transport Systems

Current practices by planning agencies for identifying major recharge points are not in accord with well-established hydrogeology principles. If the errors are serious it could lead to restrictions and regulations directed at land uses in the wrong places within the watershed. Little is known of the ground-water discharge points within the Bay as well as the previous problem of recharge points.

7. Implementation

There is a general feeling that more research is needed on how best to implement that which is already known. That is, we often find that adequate basic information is in hand and yet it is impossible to effectuate change because of inappropriate means for "moving from here to there".

8. Lake Winnebago

There is still very little known about the contribution of the waters of Lake Winnebago to the lower Fox to the Bay. As more control is exercised over point sources in the Fox River, the significance of the outflow from Winnebago will increase markedly. More effort should be devoted to an understanding of this potential contribution.

9. Communication and Training

There is the belief that Sea Grant communication and advisory services -- while excellent in their traditional role of focusing on water and those who use the water -- are not well suited to assisting those whose use of the land holds implications for water quality in the Bay. There is a need for work on ways to improve this aspect.

10. Jurisdictional and Institutional Problems

One important fact is that while federal responsibility covers the water resource, it is local responsibility which comes in to play with respect to land use. The physical linkage is therefore at odds with the institutional arrangements, and this disparity causes problems in the design of pollution control programs, and in the implementation of same.

11. Methods for Improved Measurement of Benefits and Costs

Because of the probable increased significance of toxic materials in the Bay, the benefits from reduced pollution take on an intangible character which many will find difficult to comprehend. Additionally, the costs of pollution reduction are often badly specified. There was a feeling that more research should be conducted in this area.

12. Future Land Uses and Their Implications for the Bay

There is a need to look beyond the next few years in terms of possible significant changes in land use and what that will mean for the Bay. If food production increases substantially this may imply a large increase in the application of chemicals and in the intensive cultivation of marginal lands; both changes would hold serious implications for water quality in the Green Bay region.

Priorities

After selecting the above twelve items as important research areas the group proceeded to rank them in two dimensions: (1) importance, and (2) urgency. By importance we mean their potential role in solving a crucial information problem, while by urgency we mean those which should be undertaken first.

A simple voting procedure was employed for each dimension and the results are shown in tables 1 and 2.

TABLE 1: RANKING ON IMPORTANCE

Research Area	Votes (3 votes cast per member of group)
Hydrologically Active Areas	8
Surface Transport Systems	5
Future Land Uses	5
Groundwater Transport	4
Lake Winnebago	3
Communication and Training	3
Jurisdictions and Institutions	2
In-Lake Phenomena	2
Toxics and Their Sources	1
Methods for Benefits and Costs	1
Implementation	1
Air Emissions	1

TABLE 2: RANKING ON URGENCY

Research Area	Votes (1 vote cast per member of group)
Hydrologically Active Areas	6
In-Lake Phenomena	3
Surface Transport Systems	1
Lake Winnebago	1
Jurisdictions and Institutions	1

TASK GROUP NO. 5-WATER USE IMPLICATIONS FOR GREEN BAY

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Mr. Jerry McKersie	Mr. David Smith
Dr. Dale Patterson	Mr. Bill Zabor

Introduction

A diverse group of approximately one dozen people addressed this subject as part of the overall workshop effort. Participants included regional planners, paper industry and public information officials, an agricultural journalist, a fishery biologist and an applied mathematician experienced in water quality modeling. Following a rather wide ranging preliminary discussion, the group identified six major uses for the waters of Green Bay. They are:

1. Transportation-Navigation
2. Water Supplies for
   - Municipalities
   - Industries
   - Power generation
3. Fisheries/Biological Resources
4. Minerals
5. Recreation/Esthetic Appreciation
6. Waste Assimilation
   - organic
   - inorganic

The discussions which immediately followed were focused on those uses where scarcity might develop and where conflicts associated with multiple use might occur. A scarcity of waste assimilation capacity was identified along with harbor and marina facilities as examples. Multiple use conflicts identified included use of the Bay both for fishing and for waste assimilation. This stage of the group discussion was very effective as a foundation for later consideration of research needs.

Research Needs

Seven separate research needs were identified. They are:

1. What are the economic, institutional and social issues associated with public water supply needs?

Potable water supply, usually from groundwater, is becoming more limited and more expensive in a number of areas in the Green Bay watershed. Examples of this include:

+ the Marinette-Menominee metropolitan area where arsenic from an industrial source has created problems

+ Door County where malfunctioning septic tanks on shallow top soil have created groundwater pollution

+ metropolitan Green Bay where increased pumping in a concentrated area has significantly lowered the aquifer levels. (As a result, a regional study has recommended the creation of a metropolitan commission to supply high quality water from Lake Michigan through an overland pipeline.)

Existing experiences with water conservation techniques in other parts of the country, such as water-conserving shower heads and toilets in private residences, were identified as sources of relevant information.

Proposed for possible use here were community wide changes in water distribution and use policies. An example is the installation of a dual water supply system in new developments to provide not only a limited supply of potable water but nonpotable water (gray water) which could be recycled in tiolets and other areas where potable supplies are not required.

Other water uses, such as supplemental irrigation for agricultural purposes and industrial use were also discussed. The consensus of the group was that social science issues associated with this problem merited more research attention than either physical or life science issues.

2. Predicting persistence of toxics in the Green Bay ecosystem.

This problem was considered to be a particularly important one which will have a significant impact on all elements of the local culture -- ranging from eating habits to leisure time activities to future growth characteristics of the regional industrial base. Progress toward achieving a substantial reduction in the amount oxygen consuming wastes from both municipal and industrial point sources, as well as rural and urban nonpoint sources, was reviewed and considered to be generally satisfactory. Point source organic waste releases are not expected to be a significant research problem in the near future. Nonpoint source discharges will have many social science research opportunities, but they are more readily understood and identified in contrast to the toxic releases. The group concluded, therefore, that major efforts will be required to understand the waste assimilation characteristics of the Bay as they relate to toxic materials including chemicals such as PCBs. Socio-economic questions, including attention to water based recreation and fish consumption habits, need to be better understood. The identification and monitoring of toxic chemicals should be initiated and maintained over a sufficient period of time to establish a basis for effective management necessary to maintain both public health and stability of the aquatic ecosystem. Specific problems associated with toxic releases need to be identified and screened, such as (1) bioaccumulation, (2) temporal and spatial distribution in the Bay waters and bottom sediments, and (3) the primary sources of toxics to the Bay ecosystem. This will assure that critical problems are understood early on and facilitate action in seeking their solution. Also emphasized was the need to develop both a qualitative and quantitative predictive tool or model relating physical, biological and chemical interactions in the Bay associated with toxics.

3. Alternative developmental futures for Green Bay water use.

Great difficulties exist in predicting long-term (in excess of ten years) requirements for bay water use with any assurance. The task group concluded that futuristic studies of alternative scenarios for the Green Bay region which might occur with different combinations of industrial development, agricultural use, human population changes and energy availability would be desirable. Political, economic and technological actions external to this region -- such as a change in international oil pricing, or water shortages elsewhere in the nation -- would have a major impact on such studies and should be included.

4. Dredge spoil disposal implications.

The environmental, economic and social implications of dredge spoil disposal in the Bay and/or on nearby land were identified as significant research problems. The continued maintenance of Green Bay as a harbor will create dredge spoil disposal problems on into the distant future. As a result, it seems necessary to better understand all elements of this problem. Specific attention must be given to potential institutional conflicts.

5. Water-based recreational demand.

This research need was considered important since several new actions have or are about to change the Bay-centered, water-based recreational mix. The completion of the new interstate highway is expected to reduce travel time between Milwaukee and Green Bay by approximately twenty minutes. As a result, an increased number of people from the Chicago and Milwaukee metropolitan areas may be expected to use this recreational resource. Also, the water quality is expected to improve as a result of the extensive investments in reducing organic waste discharges upstream in the Lower Fox River. These factors plus increasing leisure time, affluence and rising demand for water-based recreation will also contribute to increased recreational use of the Bay.

For these reasons, a more diverse recreational fishery is expected to develop along with the expanded opportunities for sailing, water skiing and perhaps swimming in the lower Bay. Water-based recreational characteristics developing in a few years may require additional sensitivity to both safety and zoning questions, such as exclusive fishing or water skiing areas.

6. Energy production issues -- economics and the environment.

Rising energy costs are expected to provide increased incentives for research associated with energy generation in the watershed. Examples of research opportunities in this area include:

+ the possible use of low head dams on tributaries to the Bay for developing pumped storage units which would provide additional peak power at reasonable capital and operating costs

+ wind generation of electric energy based on the comparatively dependable breezes over the water

+ the development of environmentally sound criteria for siting new electrical generation power plants which have a high probability of being constructed on the shores of the Bay and/or Lake Michigan

7. A biological assessment program for water quality measurement.

The task group concluded that a need exists for developing and maintaining a long term, biologically based program to monitor Green Bay water quality. Recent judgments have indicated that current chemical and physical water quality measurements can probably be replaced with this economically efficient and environmentally sound monitoring technique in the future.

Research Needs Priority

Following the identification and discussion of research needs for water uses of the Bay, an attempt was made to identify priority study areas. Each task group member independently ranked the seven needs. A composite of these individual rankings resulted in the following recommendations:

Priority #1: Predicting persistence of toxics in the Green Bay ecosystem.

Priority #2: Public water supply conflicts: economical, institutional and social issues.

Priority #3. Alternative developmental futures for water uses - growth of industry, agriculture and population.

Others: No preference was apparent from the group ranking. They

TASK GROUP NO. 6-FISHERIES

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More than half of the fish harvest from Lake Michigan has been from Green Bay waters even though the Bay constitutes a very small proportion of the Lake's area. The Bay and its productive capacity is critically significant to food production and recreational fishing from Lake Michigan waters. In addition, fishes are good integrators of environmental quality and also themselves alter the aesthetic quality of the Bay. Maintenance of healthy fish production depends on high quality environments in the streams, marshes, and open waters of the Bay. Continued use of the Bay for its fish resources puts a premium on high quality as a management goal for the Bay. Our purpose is to help provide the necessary research and information for the rehabilitation, maintenance and utilization of fishery resources of the Bay.

The Green Bay fisheries program offers many areas for research concern. Green Bay fish resources are expected to become more significant for food, recreation, and aesthetics. Research on both species and community levels should be organized about these uses. The fish community in Green Bay is an interesting mixture of warm water, cool water, and cold water species. These include both native and exotic fish. Population dynamics of whitefish, suckers, and perch are currently being studied, but population characteristics of other species are not known. Smallmouth bass and northern pike populations are totally uncharacterized. Fluvial contributions to the fish stock have not been assessed. Effects of exotic species such as salmon, alewives and smelt upon the Bay community are not fully evaluated. Habitat requirements of perch and whitefish have been documented for most stages of their life history, but for other species habitat evaluation is incomplete. Some species such as carp, bullheads, and alewives may influence the habitat of other significant or formerly significant species such as perch and lake herring. Underused species programs have been proposed but life histories of burbot, round whitefish, and suckers are incomplete.

Important areas of fisheries research concern the basic biology and habitat requirements of individual species that are important to the fisheries and to the ecology of the Bay. Species of special interest include whitefish, alewife, lake trout, suckers, carp, yellow perch, and burbot. Also, there are research needs on the interrelations among the fishes in the Bay and between the fish and the other biota. The importance of understanding the impact of exotic species such as alewife and carp on the ecosystem was stressed frequently since they are suspected as having significant negative influence on valuable fishery resources such as the yellow perch. Data needed on individual species include population dynamics, distribution and movement, food web dynamics, and habitat requirements for successful spawning and nursery areas. Studies to delineate the stream dependence of key species and the importance of the Bay to fish resources of the open lake were judged to be important but less important than studies on individual species and their interaction with each other in the Bay.

Population dynamics studies presently underway should gradually be assumed by DNR as a monitoring responsibility for making annual decisions on exploitation quotas for the Bay. Economic research would help understand and perhaps resolve allocation problems among users. Some type of survey to determine user expectations from the fishery would be helpful. Supplementing natural reproduction by aquaculture and reestablishing native stocks were considered important as were the potentials for lake ranching of selected species.

PCBs and other pollutants can still limit the human use of important species in the Bay. Research indicates that alewives are particular concentrators of PCBs. Management strategies to shift the ecosystem toward native fishes might reduce PCB levels in lake trout. Harvest strategies to use smaller fish could produce a marketable product but might adversely affect the fish stock if natural reproduction remains a goal. Efforts to clean up and prevent the input of specific chemical pollutants to the Bay should be stressed.

The potential impact of developments on the Bay, especially those that would influence the inshore spawning and nursery areas, was stressed. Especially worrisome were questions of entrainment mortalities from future power plants and modification of marshes which act as unique spawning sites.

Fisheries seemed like an especially appropriate area for increasing communication between users of the Bay because we felt increasing the users' information base and understanding would reduce unnecessary conflicts, i.e., between boaters and commercial fishermen.

We felt that often information was available to address individual problems on the fisheries of the Bay but that time was seldom available to develop critical literature reviews applicable to immediate management problems.

The production and value of the fishery is closely dependent on the activities in research areas other than fisheries. Especially important are studies considered under trophic status, environmental contaminants, and water use implications.

SEA GRANT RESPONSE

SOME REFLECTIONS ON THE GREEN BAY WORKSHOP-R.A. RAGOTZKIE

As we conclude this planning workshop, the inevitable question arises: what is to be done with the workshop proceedings and with the recommendations for future work in Green Bay that this group has worked so hard to develop?

They will, of course, be distributed to all of you, as participants, and I hope will prove a useful record of your deliberations here. But more importantly, we don't intend to quietly shelve this document. We intend to air it widely, sending copies to appropriate local, state and federal agencies as well as to our National Sea Grant Office in Washington, D.C.

Chiefly, though, this will serve as a planning document for our program. It will be used by me, as Sea Grant director; by Bud Harris, as coordinator of the Green Bay Subprogram; and by the Subprogram Steering Committee. The ideas developed at this workshop will provide important guidelines for future work and will serve as a measure of our progress in years to come. In terms of immediate application, we will use these recommendations in formulating our research program for 1979-80. We will attempt to encourage proposals addressing issues that you have identified as important during our upcoming proposal cycle.

As we wind up our two-day workshop, I have a few observations to make. One next step that has been talked about is a research conference--and I agree that we should orient future meetings to report on specific findings and progress. Although we didn't invite students to this workshop, I would urge that they become involved in future meetings of this sort. A university course or seminar tied to this program would be another important educational initiative.

Also, as we continue our Green Bay work, there will be a need to keep the public informed of our efforts and what is known about Green Bay. This job will fall on our Sea Grant area representatives, Lynn Frederick and Victoria Garsow, to a large extent. The idea of a Green Bay Expeditionary Year proposed by Clifford Mortimer, is another means of attracting public attention. But in order to catch fire, this effort would need the whole-hearted cooperation of local groups and government as well as the involvement of state and federal agencies.

To sum up, what have we really accomplished over the last two days? Well, we've come up with a research plan and we've enjoyed the chance to talk with each other and exchange ideas and information. Then, too, this meeting provided a forum for involving the Michigan Sea Grant Program, and I am looking forward to greater cooperation between our two Sea Grant programs in the years to come. The promise of closer ties with the federal and state agencies represented here is equally heartening. So, we have come up with a concrete planning document, but perhaps as important, we have sown some seeds of cooperation that I hope will bear fruit as time goes on.

In concluding, I'd like to thank all of you for your generous participation, and give a special thanks to Bud Harris and his staff for doing such a tremendous job on this workshop.

APPENDICES

APPENDIX A

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APPENDIX B

UNIVERSITY OF WISCONSIN SEA GRANT COLLEGE PROGRAM
GREEN BAY RESEARCH WORKSHOP AGENDA

Thursday, Sept. 14

12:00 - 1:45 p.m.	Registration - Community Sciences Theater Lobby
1:45 - 2:00 p.m.	Campus welcome - Chancellor Edward Weidner
2:00 p.m.	Sea Grant welcome and Review of Agenda - Dr. Robert Ragotzkie, Director, UW Sea Grant College Program and Dr. H.J. Harris, Coordinator, Green Bay Subprogram
2:30 p.m.	Present Status of Green Bay Ecosystem - Dr. Alfred Beeton, Director, Uni. of WI Sea Grant Program
3:15 p.m.	Implication of Current Pressures on Green Bay Ecosystem - Dr. John Ross, Director of Wisconsin Seminars on Resource Environmental Systems
4:00 p.m.	Task Group Identification and Charge
5:15 p.m.	Social Hour (CASH BAR)
6:30 p.m.	Buffet Dinner
7:30 p.m.	Dinner Speaker - Mrs. Lee Botts, Chairman, Great Lakes Basin Commission

Friday, Sept. 15

8:00 a.m.	Task Groups convene
3:30 p.m.	Plenary Session - Task Group Progress Reports
6:00 p.m.	Social Hour (CASH BAR)
7:00 p.m.	Dinner - Fish Boil (Participants guests of the Founders Association of the University of Wisconsin-Green Bay)
8:15 p.m.	Task Groups reconvene - (report writing)

Saturday, Sept. 16

8:00 a.m.	Task Groups Finalize Recommendations
9:00 a.m.	Plenary Session - Task Group Final Report and Discussion
1:00 p.m.	Workshop adjourns