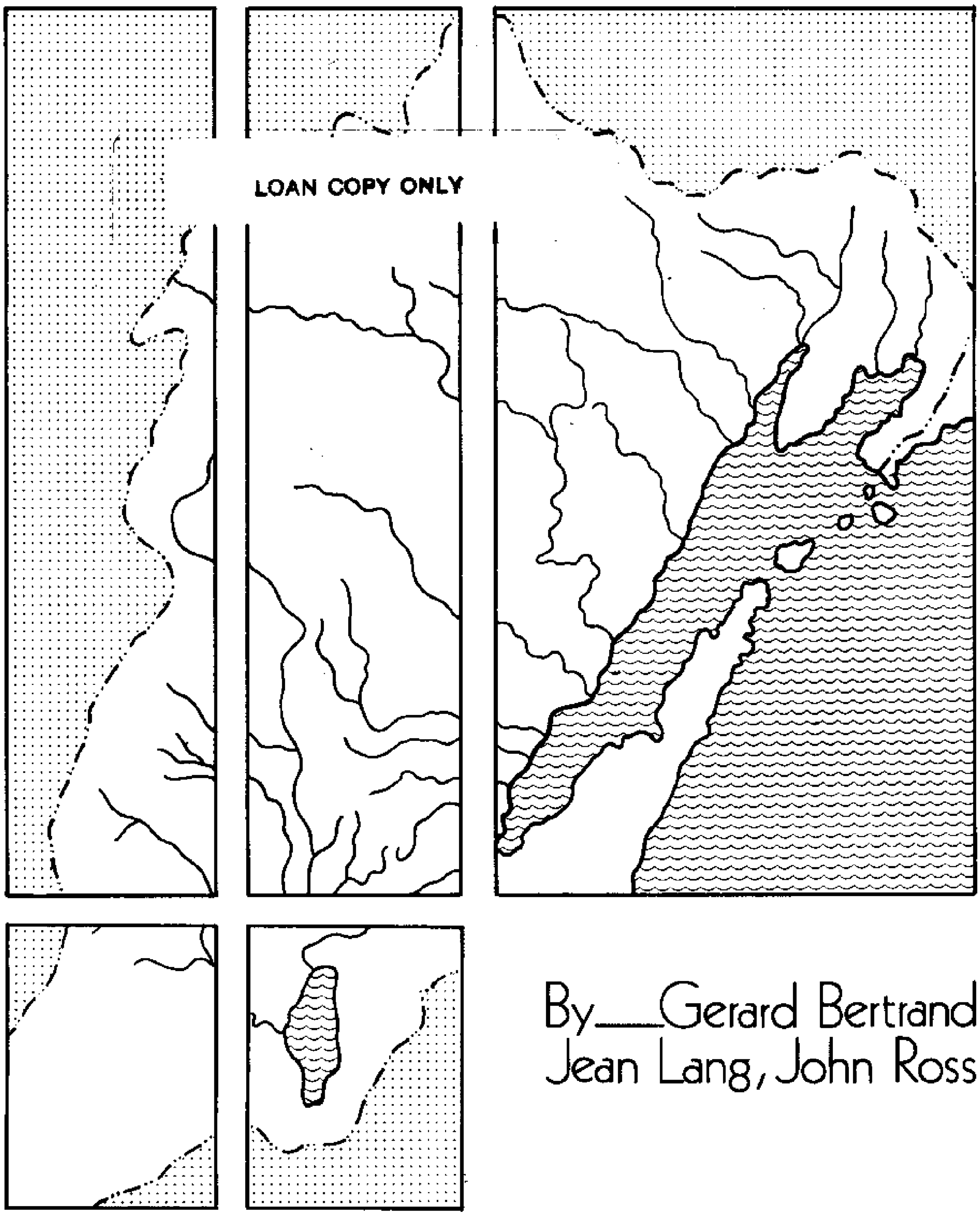
The Green Bay Watershed
Past / Present / Future



By Gerard Bertrand
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University of Wisconsin Sea Grant College Program

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UNIVERSITY OF WISCONSIN SEA GRANT COLLEGE PROGRAM

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TABLE OF CONTENTS

PREFACE

This report was initiated by the UW Sea Grant College Program in 1974 to evaluate its own past research in the Green Bay system, to review related research work by others and to determine future areas of productive research.

In order to make this evaluation, we quickly found that we needed to understand much more about the region itself, its history, its status and its possible future. Thus, the report deals with those issues as well as with the research of Sea Grant and others. Specifically, we

(1) summarize the relevant published research findings concerning the bay ecosystem;

(2) examine the probable future direction of this ecosystem;

(3) present possible alternative futures; and

(4) delineate gaps in our knowledge that must be filled before we can purposefully and positively influence the future of Green Bay.

In all of this, we tend to look at the bay itself as the dependent variable, dependent on how we use it and manage it in the future.

Looking back, we see that many changes have already occurred in the bay and its watershed. Over three hundred years ago, Green Bay was an historic trade and access route for Indians, fur traders and explorers. The bay and its Fox River pointed like an arrow into the heart of the continent, and on these waterways men moved between Canada and the Mississippi River.

Although the Green Bay region had great natural wealth, it remained sparsely populated until Wisconsin achieved statehood. Then followed a history of settlement and development that is a classic example of America's pioneering philosophy of resource exploitation. The early settlers were wasteful and ruthless in their harvest of forest, land and fisheries and in their harnessing of water resources. In the context of the time, they could afford to waste, for land was plentiful, settlers were relatively few and conflicts in resource use were minimal:

In 1884, a promoter of Wisconsin wrote:

> "The custom of using maple wood for fuel, without paying any regard to the planting of trees for succeeding years, has, in some localities, thinned out that species of trees and caused the fuel to bring a higher price in the market; but the forests are practically inexhaustible, like all of the resources of this great state. If it becomes a matter of necessity to protect the rights

of posterity in regard to trees, the legislature will pass a law looking to the judicious use of the axe, to prevent a destruction that will be felt in after years. This may become necessary, but it will not prove so for years to come. Wisconsin is still a new state and more in need of absolute development than of laws restricting any branch of progress."

In the last century, the bay has been a major producer of commercial fish; the forests of its watershed have yielded millions of board feet of saw timber and pulp logs; its farms have raised crops and livestock in abundance; its coasts and inland lakes have been a recreation destination for millions of people; and its manufacturing industries have produced quality paper, wood and metal products.

But during this time the bay has been a receptacle for ever increasing amounts of municipal and industrial wastes. Although the less populated northern half of the bay has remained relatively clean and continues to support a viable commercial fishery and attract outdoor recreationists, the lower end of Green Bay is now heavily polluted. It suffers from excessive nutrients, algae, organic matter, suspended solids, discoloration, odor and bacteria. Communities of pollution sensitive benthic (bottom dwelling) organisms have been eliminated in some places and dissolved oxygen levels often approach zero in the lower bay during the summer.

Throughout the bay's length, shoreline development for summer homes threatens the bay's littoral (coastal) zone; and the effluents from industry, agriculture and municipalities threaten the assimilative capabilities of the bay. As a result, the ability of the bay to produce wildlife, including waterfowl and sport and commercial fisheries, is in jeopardy.

Different systems of land and water use at the local level could change this situation. However, what the future holds for the bay depends as much on trends in the national and regional economy as it does on happenings in the Green Bay watershed. Things like the effects of inflation on population growth and industrial expansion in the Fox-Wolf Valleys, increased demands on agricultural lands to feed the nation and the world, decreasing supplies of fertilizer, increased reliance on wood proucts in light of chemical shortages, recurring shortages of gasoline and the implications for the recreation and freight transport industries in the region, and possible relaxation of environmental standards — these things are all critical forces of a yet largely undetermined magnitude.

It seems essential that their potential effects should be at least considered when laying out intricate and specialized studies that aim for better water quality in Green Bay.

SUMMARY

By any definition, Green Bay is one of the nation's important estuaries. A major geographic feature of Wisconsin and Michigan, straddling the 45th parallel, the bay is a significant natural resource. It is a recreation area, a fishery, a commercial waterway, and it contains a highly productive biological system.

But it seems to have been taken for granted by men intent on their purposes.

Since the time of settlement — 150 years ago — the Green Bay system has been changed drastically. Whether for good or ill is a matter of opinion, but changed it has been. And the trends continue.

The changes are largely the result of two major activities:

(1) Heavy use of resources in the region; and

(2) Use of the surface water as a pollution sink, causing a progression of poor quality water up the bay from south to north as time goes on.

The interaction of resource use and pollution has caused a depletion of natural resources, including some that would have the capacity to renew themselves under less stress. But it has also vastly changed the population dynamics of an array of living species in the bay.

There are many examples of man's ability to change the natural scheme of things, and he probably doesn't give that much thought to the consequences of his actions until there is evident a series of gross changes in his own habitat. It is possible that a critical point of change is being reached in the condition of Green Bay.

The authors suggest it is time to ask a series of overview questions about Green Bay:

--Are the resource management and pollution control strategies we are currently using adequate and realistic in terms of the carrying capacity of the bay's system?

--Are amounts and rates of physical and biological change in the bay such that we are crossing thresholds of no return?

--Is Green Bay merely an appendix to Lake Michigan, isolated from the main lake, or will the pollution in the bay gradually infect the larger system?

--Considering that the bay is naturally shallow and nutrient rich, are our expectations for improved water quality in Green Bay reasonable?

--Are the problems of the bay unavoidable, or is the deterioration largely the result of our inaction?

This summary highlights what Green Bay is and what we know about the changes occurring there. Our intent is to describe things, not to pass judgment on the past or the future.

The Geographic Setting

Green Bay is 119 miles long and has an average width of 23 miles. Few areas of the bay have depths over 131 feet. Like Lake Michigan, it is a remnant of the last glaciation, so it is geologically young. Although Green Bay appears to be an appendage, almost isolated from Lake Michigan, it is a significant part of that Great Lake. About one-third of all the land that drains into the larger lake drains through Green Bay. Eleven rivers and streams enter the bay, but one stands out. The Fox River is the most significant because of its volume and because of its pollution load. The banks of the Fox are heavily industrialized and the river receives effluent not only from numerous factories and mills, but also from a population of approximately a half million people.

Water Movement

The water in the bay has several characteristics of signal importance in any management strategy:

(1) The water level is now about 580 feet above New York mean sea level. This represents a dramatic increase from the level of ten years ago. The water level has fluctuated widely over the years. Since 1860 when records were started, there has been a variation of almost seven feet between extreme high and low levels. The long-term water level fluctuations are due to climatic variations. To a very limited degree the water levels can be controlled at the major inlet for Lake Michigan (Sault Ste. Marie) and through the southern outlet of the Chicago canal. But the process is extremely slow, and in light of current high levels would have an insignificant effect. Although levels have dropped slightly over the past year (1974), predictions are for levels to remain high or go even higher as the trend toward a wetter climate continues.

(2) Because of its elongated shape, Green Bay is subject to basin oscillations on a short-term scale. These oscillations, or "seiches," are essentially caused by the earth's movement. However, they are modified and enhanced by wind, sudden changes in barometric pressure and other physical factors. A seiche may change water levels a foot or more in a few hours, six miles up from the mouth of the Fox River.

(3) Currents in the lower bay tend to be counter-clockwise, moving southerly on the western side, then swinging east and north. There are some pockets in the lower bay with limited water movement.

While the water from Green Bay does find its way into Lake Michigan, the bay tends to have a hydrodynamic life of its own. When the water does exit, the outflow is carried south along the Wisconsin shore.

The Bay Bottom

The bottom of the bay varies from mud, through sandy mud, to sand, clay and rock. Since 1950, the lower bay has become much shallower, due to increasing rates of sedimentation. This deposit has reached a depth of four feet in some locations since 1950, with an average of two feet of deposit throughout the lower bay region.

The Fox-Wolf River basin is roughly 6,250 square miles and it is now estimated that each square mile contributes 40 tons of sediment to the bay each year. The natural characteristics of the bay, plus the rate of siltation mean:

(1) Green Bay's shallow waters will continue to be turbid, and

(2) Dredging will of necessity be a continuing practice.

Dredgings from the mouth of the Fox River and the inner ship channel contain polluted sediments. Authorized dredgings are now deposited in a series of marsh areas. Some landowners, however, carry out illegal dredge and fill activities in the area each year that violate permit regulations.

One other bay bottom feature could produce an environmental impact in the future. Research started in 1969 uncovered major manganese deposits in the form of small pellets in the upper bay. The deposits have a relatively low percentage of manganese compared to other freshwater deposits, and they are lacking in other trace elements that have commercial value. Present foreign sources of manganese are less expensive, but the Green Bay deposits can be considered a reserve and underwater mining is not out of the question. The special value of this deposit is that the manganese occurs in a pellet form, making it an ideal catalyst.

Water Quality

Two significant water quality problems stand out in Green Bay:

(1) Dissolved oxygen levels, and

(2) Nutrient enrichment, with accompanying algae production.

The Fox River outflow is the prime determinant of oxygen levels in the lower bay. In summer, the Fox is a source of oxygen-depleted water. Depressed oxygen levels extend from Appleton, through the lower Fox and out into the bay. Oxygen levels in that part of the bay drop to zero, and aquatic life decreases accordingly. Oxygen levels improve in the fall in the river and in the lower bay. In winter, a critically low oxygen level develops in the middle bay. There is some indication of improvement in oxygen conditions in the last few years. This may be due to pollution abatement, but it may also be due to the diluting effect of increased water levels and thus the reduction of biochemical oxygen demand.

Man's activities have added significant amounts of nutrients (phosphates and nitrates) to the bay. Phosphates are critical in this situation. They are only part of the reason for the abundant growth of algae in the bay each spring through fall, but a decline in phosphates could limit algae growth.

In 1971, the summer algae bloom in Green Bay extended 15 miles up the bay from the mouth of the Fox River; in 1972, 20 miles; and in 1973, the bloom had extended 30 miles up the eastern shore. It is unknown how long this rapid rate of growth will continue.

Diatoms are a major component of the algae community and predominate during the winter and early spring. Beginning in May, the numbers of green and blue green algae increase, reaching a peak in late summer. Because of the high production of algae in the bay, the system could be described as overfed and aging rapidly.

There is no doubt that the nutrient loadings that come from the mouth of the Fox River are primarily responsible for the eutrophic (nutrient rich) condition of the lower bay. The lower Fox Valley is one of the most heavily populated and industrialized areas in the state. Even without the tremendous load of industrial and municipal enrichment, the water from Lake Winnebago above the industrial belt is already in a significantly degraded state and carries heavy nutrient loads. Much of that phosphorus comes from urban and rural runoff. Phosphate will continue to be a significant problem in spite of enforcement and pollution abatement action against industrial and municipal sanitary sewers. To solve the problem will require control of agricultural sources and urban runoff. As with phosphorus, nitrogen will continue to be a problem even after pollution abatement reduces nitrogen loadings from industrial and municipal forces, because farmland is a source and because the blue green algae fix nitrogen within the lower bay.

While oxygen and nutrients stand out as water quality concerns, there are a series of other issues that cannot be ignored, either because they might develop into a major environmental crisis or because they may be critical in terms of a chain effect in the environment.

(1) Green Bay's ecosystem has been impacted by chlorinated pesticides. The drainage basin is a major agricultural area. Although pesticide levels appear to be below levels of major concern, they are sufficiently high to warrant continued monitoring to determine rates of decomposition within the system.

(2) The potential problem of the industrial plasticizers known as polychlorinated biphenyls (PCBs) has not been adequately addressed for Green Bay. Like the chlorinated pesticides, PCBs appear to be concentrated in aquatic organisms, like fish and in bottom sediments. Preliminary studies on the bay and recent studies on southern Lake Michigan indicate that this environmental pollutant needs careful attention.

(3) The western shore of Green Bay is low, with indistinct shorelines, and the area of its littoral zone contracts and expands with rising and falling water levels. A decade ago it was a broad band of aquatic vegetation extending from the city of Green Bay to Escanaba, Michigan. This classical littoral zone played host to a horde of waterfowl, aquatic birds and mammals, as well as a complex community of plankton and nekton. This habitat has been drastically diminished under the recent high water levels, and with it, the associated animal community. While the biological recovery of this zone is not a long-term problem, man's manipulation of the shoreline during this period of high water could do much to postpone recovery. Whatever one might say pro or con about present water levels, there is no question that the current habitat loss is exceedingly heavy.

The littoral zone can also be described in this area as a tension zone for man. To the extent that there is development in this area, both high water and low water cause problems. In periods of low water, there is anger over regulations against dredging and during times of high water, there is argument over shoreline fills and erosion protection structures.

Biological surveys of Green Bay show that the lower bay is heavily polluted and the middle bay has gone from lightly to moderately polluted. This evidence comes primarily from studies of benthic organisms — creatures that live on lake or river bottoms. While they are not necessarily in themselves a water quality issue, these animals are good indicators of water conditions because their kinds and numbers change with the changing environment. Even minor changes can be measured. In Green Bay there is no need to search for subtle changes. The gross effects of the Fox River system are strongly reflected in the benthic zone. The first quantitative survey of benthic organisms was taken in lower Green Bay in 1938 and 1939. By the time of the next major survey in 1952, there had been a dramatic increase in the number of pollution-tolerant worms. Additional work in 1971 showed that a steady encroachment of polluted conditions up the bay and along the eastern shore had occurred.

It is clear that Green Bay is following the path of Lake Erie and that many of the changes earlier documented in Lake Erie are now occurring in Green Bay. Benthic fauna can continue to serve as a significant indicator of the progress or regression of polluted conditions in the bay.

Status of Resources

Of the resource-based industries in the watershed, we have considered only those with significant impact on the bay. Thus there is no discussion of machine manufacturing or several other important industries of the region.

(1) Fisheries

Commercial fish stocks were once far larger and more diverse than at present. Herring and whitefish inhabited the shoals throughout the bay. Trout occurred in the deeper, colder waters of the northern bay. Walleyed pike, pickerel, sturgeon, suckers, bass, perch and catfish swam the shallow marshy waters at the heads of bays and mouths of rivers. This distribution began to undergo changes as early as 1850. Fishermen who located a large population of fish would simply fish until the stock was used up.

Pollution was also an early factor. In 1880, a writer noted a large mass of sawdust, two miles broad and many miles long, floating about in the bay. Perch catches were on the decline by 1900. The lake herring catch peaked around 1905. And when, in the early 1900s, the economic focus of the region shifted from lumber cutting to papermaking, there followed fish die-offs as pulp wastes reduced oxygen levels in the lower Fox River and lower Green Bay.

Up until the 1920s the depletion of fish stocks was a story of pollution and removal of habitat, overfishing and the vagaries of the physical environment. But another factor was added in the 1920s — introduction of exotic species. The first troublesome newcomer was the German carp, planted throughout the state in the 1880s and 1890s. Today it is well established along the shallow, western shore. Following the carp came the adaptable ocean smelt; then came invasions of the sea lamprey and the alewife through the St. Lawrence Seaway.

Throughout the 1950s and 1960s, the fisheries could only be described as ailing. Lamprey control and the introduction of salmon and trout have since given a base for sports fishing in the states bordering Lake Michigan, but most of this activity is out on Lake Michigan proper. As of 1974, lake trout were still not reproducing themselves. Both salmon and lake trout populations remain dependent on yearly restocking programs — they are there only by the grace of state and federal revenues. Today the Green Bay commercial fishery depends largely on the harvest of alewife for fish meal and other purposes and on the whitefish harvest in the northernmost reaches of the bay.

Recreational fishing on lower Green Bay is now poor. The northern bay is a more popular sport fishing area and holds more promise for the future. Given optimum environmental conditions, it might take generations to reestablish the once grand array of natural fish. Today, throughout the Lake Michigan area, fish management policies reflect the belief that the need to develop immediate economic opportunities, such as sport fishing facilities, overrides the longer-range need for rehabilitation of a balanced fishery that could provide both sport and food. There is obviously room on Green Bay for both commercial and sport fisheries, given the opportunity. Solving the fishery problem would require considerably more knowledge than we have about fish population dynamics and considerably more attention than we have to date given it.

Because of pollution, overfishing and competition from exotics, several species may be out of the picture: the lake sturgeon and the deepwater ciscoes. The lake sturgeon, sometimes exceeding seven feet and 300 pounds, has been nearly exterminated. It does now receive limited protection under the Endangered and Threatened Species Act of 1973. In addition, the diversity of deepwater cisco (or chub) species that once inhabited the bay has now been essentially reduced to a single species, the bloater chub.

(2) Agriculture

Early agriculture in the region was characterized by wheat farming, followed by a trend to raising livestock. By the turn of the century, the Fox River Valley and the lower Wolf had become major cheese-producing areas. Those valleys have good agricultural soils that support vegetable production and corn. Poor soils of the northern areas of the basin make agriculture more difficult. There is now a trend toward reversion of this land to forest. The decline of farm acreage is probably a fairly permanent net loss of farmland. Farms are now, however, practicing a more intensive agriculture which depends heavily on fertilizers, pesticides and mechanization.

Agriculture in the watershed has a number of impacts on the bay itself. For example, as the number of cows per dairy herd increases, there is an increased concentration of animal wastes on the land. One tributary of the Fox River drains approximately 35,000 acres of primarily agricultural lands and receives an estimated phosphorus load of three pounds per acre in the spring. Rural runoff is the major phosphorus contributor to the Fox River during the spring. Most of it comes from animal waste washed off the frozen fields during a few weeks of spring rain and snowmelt.

A look at the landscape might indicate that erosion and siltation are not major problems in the Green Bay basin. But even minor erosion in such a large watershed has a significant impact on the sediment sink area, that is, the bay. Thus, rapid filling of the lower bay has occurred, as described earlier. The present soil conservation system is limited by the fact that it can only treat erosion on a voluntary farm-by-farm basis. In addition, erosion control is intimately linked with land use control, a much contested issue. The solution to surface runoff does not appear to be waiting just around the corner.

(3) Forestry and Paper

By the late 1870s, the mouth of every log-producing river in the Green Bay region was lined with lumber and shingle mills. Oshkosh, with 24 mills on the banks of the Wolf, was "sawdust city." By 1890 pine stocks were down and mills were turning to hemlock. By 1920, Wisconsin was entering the era of the pulpwood log — spruce, fir and later, aspen, which was the dominant pulp species by 1950. While the contemporary thrust is pulp and paper, the demand for wooden products, such as hardwood molding, is increasing.

For the first time in modern times, there are shortages of various paper products. There are speculations that the rising prices will make expansion economically feasible for some mills for the first time in many years. Mill expansion on the Fox River, or other rivers of the watershed, could mean an increased waste load to the bay unless pollution controls are strictly enforced. Currently there is strict enforcement. This factor, plus the current nationwide recession has had some dampening effect on mill expansion plans.

Future growth in the paper industry could mean increased demand for the pulp woods that keep the mill going. Aspen now comprises at least 50 percent of the region's pulpwood. Within 30 years, aspen will be harvested to the hilt of its allowable cut. Either pulpwood foresters must make the decision to maintain their aspen forests artificially through site treatment or the papermills will need to adapt to handling increasing amounts of other hardwood pulp.

In the nineteenth century, wholesale timber harvest of the watershed and the associate forest fires were followed by erosion. Some of the heavy sediments were trapped behind the numerous dams, but much went into the bay. That period also saw a decline in the natural recharge of the ground water table. The dams, built to help the water-borne movement of logs, restricted fish movement up the rivers. The impacts of lumbering, however, have declined since the decline of big lumber operations and the development of county forests with regular management.

But in the pulp and paper industry, environmental impacts are still a major problem. In 1967, 90 percent of the BOD loading entering the lower Fox came from industrial and manufacturing sources. Although there has been some noticeable progress and improvement in BOD loadings in the lower Fox, abatement is not progressing as rapidly as had been forecast. Enforcement and adherence to present pollution control standards is necessary to bring a major favorable change within the next decade.

(4) Recreation

Recreation is a multi-million-dollar business in the Green Bay region; in 1968, visitors to Door County alone spent over $13 million. In spite of its overall importance, recreation tends to be a marginal industry which provides low individual income and has limited prospects for expansion: Accommodations continue to be heavily oriented toward the vacation trade and are almost entirely seasonal. Most are situated on or near a lake shore and feature fishing and swimming. But both the tourist and the recreation industry have to some extent turned their backs on Green Bay, concentrating on inland lakes and streams.

It is now clear that the turbid and often choppy waters along much of lower Green Bay's shoreline would not be first choice areas for swimming and beach activities even if pollution were reversed. Fishermen, however, are more tolerant of less-than-perfect water quality. Though Green Bay could accommodate many recreational boats, it is largely unused. Part of the reason appears to be a lack of access facilities and harbors of refuge.

The people of Green Bay have, over a period of years, become disenchanted with their bay. It appears that many of them see the bay as a boundary line rather than a resource.

It will be hard for Door County to experience more intensive recreation pressure and still retain its attractiveness. Ideally, some of the pressure should be transferred from the Door County side of the bay to the western side. It should be pointed out, however, that the land has a different character there, i.e., the wetlands. Given some relief from high water, the wetlands have a diversity of wildlife unmatched in most other areas of the state. If properly managed and promoted as a unique natural feature, the wetlands could become a major asset to the recreation industry.

(5) Shipping

Foreign ships and transocean vessels appeared in Green Bay in 1958 with the opening of the St. Lawrence Seaway. The initial spurt of traffic has declined, however, as freight companies have favored those seaboard ports that can accommodate the increased size and container structure of newer ships. Midwestern ports, including Green Bay, are struggling with the issue of port modernization and how to keep their ship lanes free of ice in winter.

It is anticipated that interlake bulk transport of coal, iron ore, grain and stone could increase. But it does not appear that Green Bay will become congested with shipping. The trend is toward regional port development, and Green Bay will be hard-pressed to compete for dwindling general cargoes with larger, central ports like Milwaukee and Chicago.

The Future of Green Bay

From these observations of the past and present, we can make some predictions about where the bay may go in the future.

First, the bay's water quality could deteriorate at an accelerated rate due to continued pollution. This would occur because of a major shift away from present pollution abatement strategies. There is some pressure to roll back the required pollution control technology in industrial plants and additional pressure to put off the 1983 and 1985 goals of the Federal Water Pollution Control Act which call for zero or close to zero discharge.

Given this scenario, benthic organisms tolerant to pollution would continue to appear steadily up the length of the bay. Clams, snails and mayfly larvae (food for fishes) would disappear. Algae would increase in the lower bay with increased number of fish kills. Deposition of organic matter would increase, and this would reach into the middle bay. Oxygen depletion would increase in area and in duration. Recreational boating and fishing would decline. This general decline would work its way into Lake Michigan proper, particularly along the lake-side shore of Door County.

A second scenario would be a moderate cleanup of the Fox River Valley with curbing of gross municipal and industrial pollution. This involves primarily the removal of BOD loadings from the Fox River Valley.

Water quality in the Fox River and in the lower bay would improve "technically." That is, it would be better oxygenated, with less production of hydrogen sulfide. Pollutant-tolerant organisms would begin to retreat toward the mouth of the Fox River, with fewer fish kills. Fish, particularly yellow perch, would increase in number. Deposition rates might continue at their present pace, but would probably not increase.

Such a scenario would not deal with the "nonpoint" sources of pollution, particularly farmland runoff and storm sewer drainage. The lower bay would continue to be highly eutrophic and turbid. The water would be more technically cleaner than it is now, but would likely remain dirty in the people's minds.

A third possible scenario would be a program to systematically eliminate point and nonpoint source pollutants. This would include the control of storm sewer runoff and the inputs of farm fertilizers. Such control methods would greatly aid in reestablishing the bay as a recognized public resource.

At the present time, the second scenario of continued BOD removal and no control of dispersed pollutants appears to be the most likely course of action. However, economic conditions could change the rate of development of the region and could affect continued or future enforcement of pollution abatement.

A major intent of this report is to make recommendations on research needs in the Green Bay system based on a thorough study of the bay and its characteristics. Details of our research recommendations are in the final section in the longer report. In brief, we recommend more attention on:

(1) The effect of the fluctuating water levels on pollution distribution, on the biological communities in the bay and on how the water level relates to shoreline development strategies.

(2) The location, size, ownership and quality of wetlands bordering the bay and the relationship of the wetlands to the bay's productivity.

(3) The effect of farmland runoff on eutrophication of the bay.

(4) Size of fishing stock in the bay, the location of spawning grounds and the current food web as it influences fishing stocks.

(5) Verification of physical conditions as predicted by the various models developed to describe the bay.

(6) Sources and rates of sediment deposition in the bay, with additional attention to microcontaminants in these depositions.

(7) Current status and distribution of microcontaminants in the bay, including heavy metals, pesticides and PCBs.

(8) Analysis of the possibility of integrated coastal zone management.

(9) Analysis of alternative economic futures for the region and the environmental impact of these alternatives.

A research program based on further involved inventories of isolated bay problems does not appear to be a fruitful endeavor at this time. It appears to us that an integrated research approach would be more productive than a categorical and specialized approach. Such an effort should deal, in a quantitative way, with the effects of specific resource use policies or pollution abatement strategies on water quality in the bay and Lake Michigan. Such an effort should also involve greater cooperation with the state of Michigan, the managers of the northern third of the bay. By drawing together knowledge of social and economic trends, resource management strategies and the bay's physical and biological systems, an integrated approach would hopefully weld these into an effective planning tool and develop the state-of-the-art in predicting change.

In the past, Green Bay has been a resource of great value to the people of Wisconsin. It could be so again, but only foresight and the desire of Wisconsin's citizens can make it so.

PART I

Physical, Chemical and Biological Characteristics of Green Bay

1. PHYSICAL CHARACTERISTICS OF GREEN BAY

1.1 GEOGRAPHY

The Green Bay of Lake Michigan is an elongated fresh water estuary, oriented in a NNE-SSW direction. It is bounded on the south by the city of Green Bay, 44°31' N, and on the north by Big Bay de Noc, 45°54' N (Figure 1). It is approximately 119 miles (190 km) long, with an average width of 23 miles (37 km) and a mean depth of about 65 feet (20 m). Few areas of the bay have depths of over 131 feet (40 m) and the entire western inshore area is less than 59 feet (18 m) in depth (U.S. Federal Water Pollution Control Administration, 1966). The deepest point in the bay is 176 feet deep (53m), 4 miles (6.4 km) west of Washington Island (Moore et al., 1975). Including Big and Little Bay de Noc, Green Bay has an area of 186 square miles (4,212 km^2) and a volume of 11 cubic miles (70 km^3) (Ahrnsbrak, 1971). Green Bay is open to Lake Michigan at its northeast side with the Door County, Rock, Washington and St. Martin's Island separating the two. There is no submarine still between the water bodies.

Green Bay water level, which has fluctuated widely in recent years, is now about 580 feet (176 m) above New York mean sea level.

The total Green Bay watershed drains approximately 15,625 square miles (40,000 km^2) or about a third of the Lake Michigan drainage basin. Two-thirds of the Green Bay drainage is in Wisconsin and one-third in Michigan's Upper Peninsula. In Wisconsin, the bay is bordered by five counties, Door, Kewaunee, Brown, Oconto and Marinette. An additional 13 counties lie within the watershed. In Michigan, the bay is bordered by Menominee and Delta Counties and an additional four counties are within the watershed (Figure 1).

Eleven rivers and streams drain into Green Bay. Of these there are only five of major importance. Three are in Wisconsin—the Wolf-Fox system, Peshtigo and Oconto. Both Michigan and Wisconsin areas drain into the Menominee, which forms the boundary between the two states (Figure 2). The Escanaba is the only major river entirely in Michigan, with the Whitefish and Ford Rivers of secondary importance. Table 1 lists the five major drainage areas. The Fox River is the most significant river because of its volume and pollution load. The average annual discharge rate for the Fox River over a 71-year period measured 18 miles upstream from the mouth and was 126 m/sec as of 1967 (U.S. Geological Survey, 1967). The Fox River Valley is highly industrialized. It has the greatest concentration of pulp and paper industry in the world (Billings, 1966) with 19 paper mills located on the lower 40 miles (64 km) of the Fox River (Kleinert and Degurse, 1972). This industry's discharge has a human population equivalent of 1,300,000 (Wisconsin DNR, 1973). In addition, there are 14 power dams between Lake Winnebago and Green Bay (Schraufnagel, 1966).

Additional pollution loads come from municipal sewage plants, urban runoff and farmland runoff in the Lake Winnebago and lower Wolf River region. While the Fox River is the major source of degraded water, there are localized

Figure 1. Political Boundaries Within the Green Bay Watershed

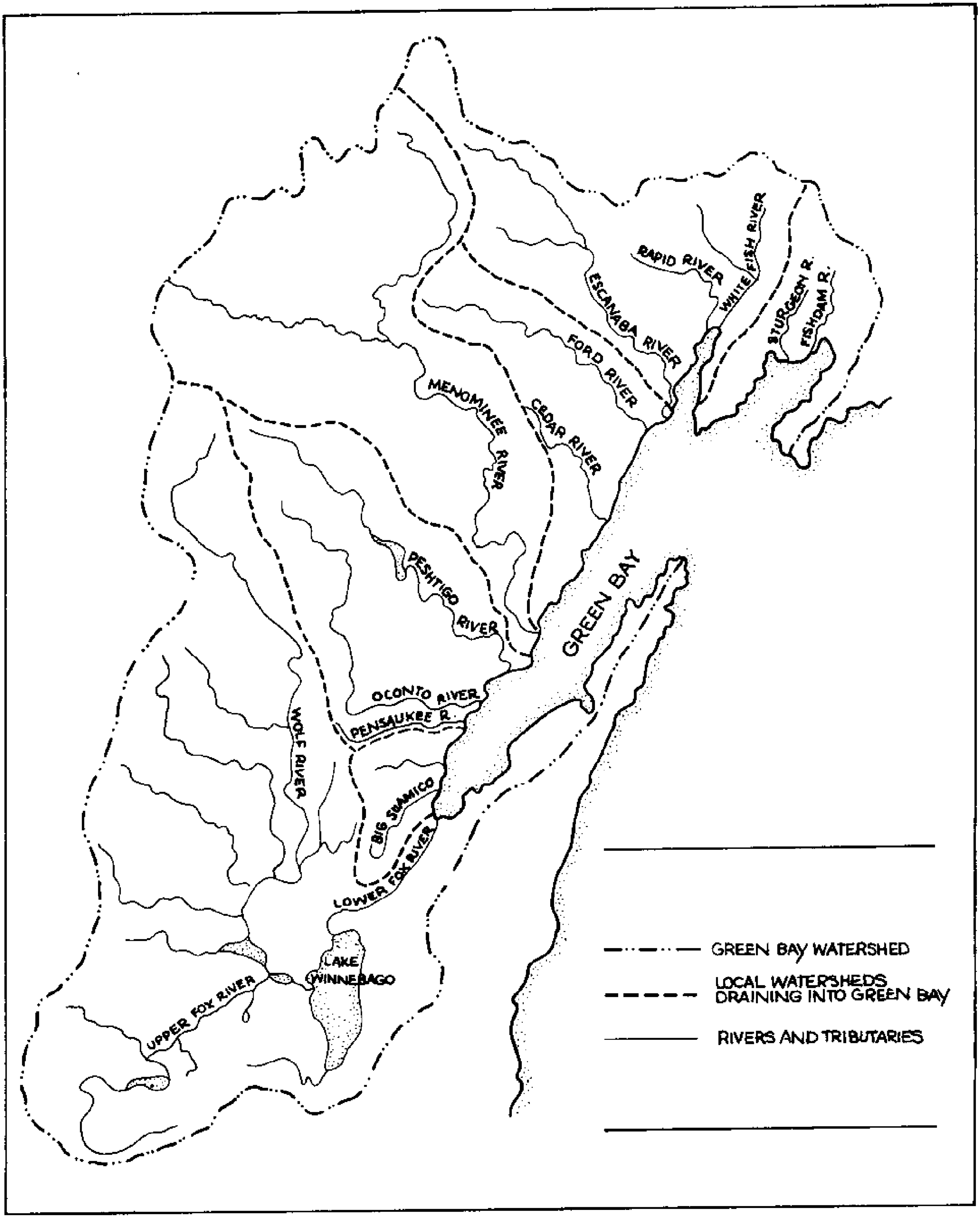


Figure 2. River Drainage Basins of the Green Bay Watershed

pollution problems in the Oconto, Peshtigo, Menominee and Escanaba Rivers. The smaller streams contribute significant loads of silt and debris, which vary in amount seasonally.

Table 1. Major Tributaries of Green Bay

River	Length	Drainage Area	Mean Discharge
Fox	322 km	16,687 km^2	117 m^3/sec
Peshtigo	233	2,991	24
Oconto	209	2,416	16
Menominee	193	10,748	88
Escanaba	185	2,382	25

from Epstein, et al., 1974

The two major shipping ports on the bay are Escanaba, Michigan, and Green Bay, Wisconsin. Escanaba is an important iron-ore loading area, and Green Bay is a major bulk and general cargo port handling about 350 commercial vessels annually (Brown County Board of Harbor Commissioners, 1972).

1.2 GEOLOGY

a. History

Green Bay is within the glaciated area of Wisconsin and Michigan. The Wisconsin portion is within the ancient lake system. The bedrock of the Green Bay area is Paleozoic in age and composed of at least three formations, the Niagara (Dilurian, dolomite) of Door Peninsula, the Maquoketa (Ordovician, dolomitic shale) on the southeast shore, and the Platteville-Galena Group (Ordovician, dolomite and limestone) on the western edge of the Bay (Hough, 1958). Other important formations within the Bay's watershed are the Prairie du Chien Group (Ordivician, dolomite), Cambrian sandstones and Precambrian granite and undifferentiated igneous and metamorphic rocks (Figure 3).

The post-glacial history of Green Bay is one of advancing and retreating shorelines (Hough, 1958). Ten thousand years ago, Lake Chicago, which occupied the present Lake Michigan Basin, was at about 600 feet elevation (183 m), about 20 feet (6 m) above the present stage. The Lake drained southward and through the Chicago outlet. As the ice continued to retreat, the Lake Michigan and Lake Huron basins combined through the Little Traverse Bay Lowlands. The combined basins maintained an elevation of 605 feet (184 m) for almost 3,000 years. Distinct shoreline features developed during the period. At the end of the Algonquin period, about 7,000 years ago, Green Bay drained in four major steps until it was totally emptied. At least one beach may be evident 90 feet (27 m) below the present lake level (Moore et al., 1973).

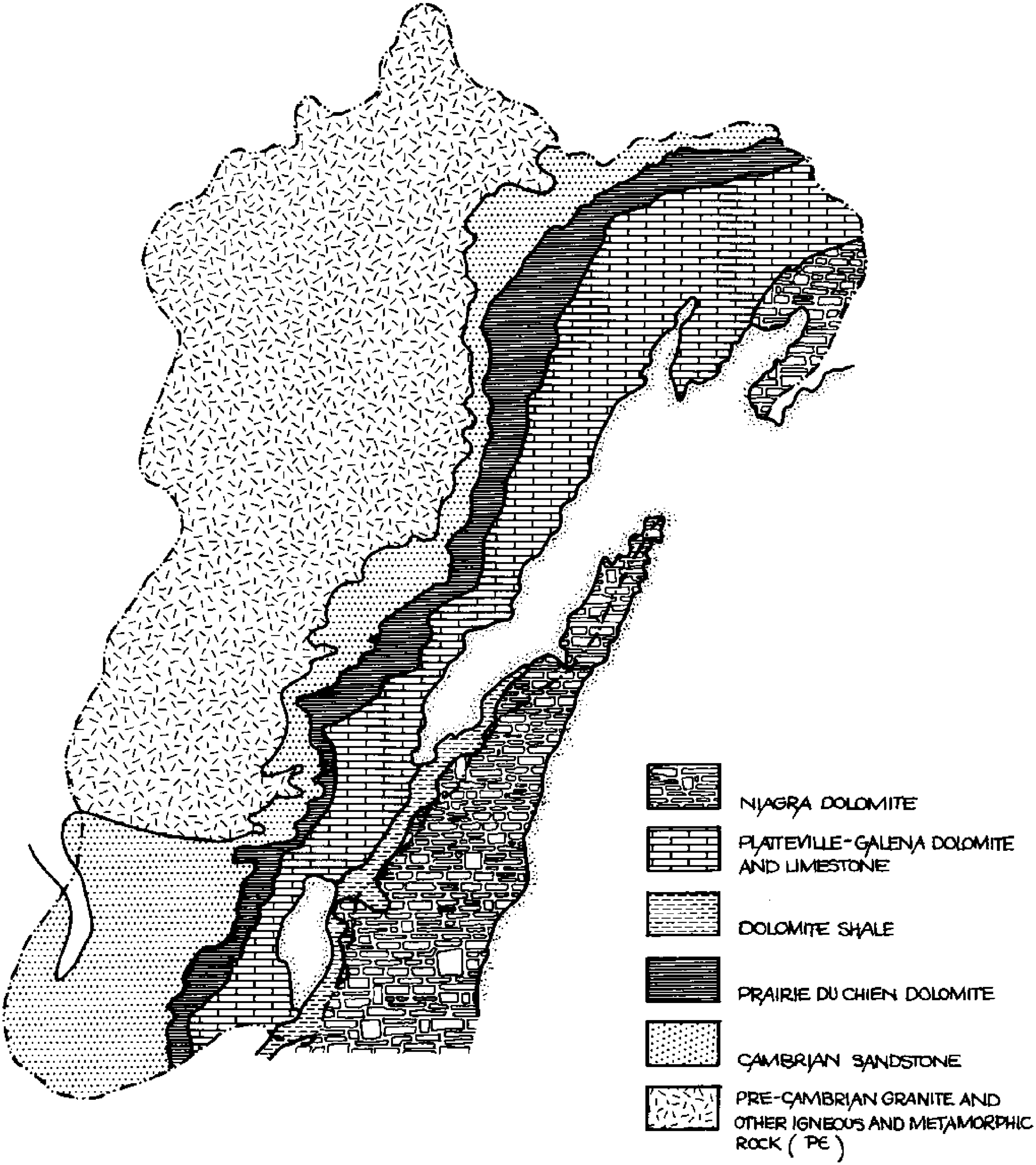


Figure 3. Geology of the Green Bay Watershed

Sixty-seven hundred years ago, with the bay completely drained, the west shore rivers probably joined to form one great north flowing river. With Lake Superior at a much higher elevation, over 1,000 feet (303 m), a major drainage developed across Little Bay de Noc in Lake Michigan. This steep-walled channel is two miles wide and 100 feet deep (30.3 m) and extends across Northern Green Bay. That the bay filled rapidly to 605 feet (183 m) about 4,500 years ago is evidenced by the fact that little major deposition or erosion occurred in the former drainage channel.

b. Sedimentation

In the summer of 1968, Moore and Meyer (1969) conducted a comprehensive geological-geophysical survey of the shallow subbottom structure and near-surface sediments of Green Bay. Using standard geological techniques and innovative geophysical techniques, they were able to map the sediment distribution in Green Bay, delineate the shallow layering of sediments in the bay, and describe the bathymetry of the bay in detail. They also accurately quantified the sedimentation that has occurred in the bay since the last U.S. Lake Survey of the Bay in 1943 (South) and 1950 (North).

A Van Veen grab was used for direct bottom sampling in unconsolidated sediments. This sampler provides a sample large enough for qualitative analysis. In areas where acoustical sampling revealed sediment layering, a gravity core, modified in the Stetson-Hvorsley design, was used to penetrate the layers. In addition to the grab, a 12 inch diameter pipe dredge was used to collect samples. Two hundred direct geological samples provided the information for the sediment map of Green Bay (Figure 4).

There are five basic sediment types in the bay: mud, sandy mud, sand, clay, and rock. Muds predominate in the southern and eastern portions of the bay. These muds are dark gray to black in color and have a high water content (75%). Wood chips and sewage are a common constituent. Recent investigations by the Corps of Engineers (USACE, 1975) found that the muds of the lower Bay were highly organic. All samples were polluted. The Corps of Engineers determined that any sediments to be dredged from this area were unsuitable for open water disposal.

Although the shallow southern end of Green Bay offers a conspicuous exception, the finer grained sediments are generally found in deep water. Muds predominate in protected areas such as Sturgeon Bay and the head of Little Bay de Noc, where deposition can proceed undisturbed. Mud thickness varies. Off Little Sturgeon Bay it may reach 30 feet (9 m) (Moore and Meyer, 1969). Organic carbon is high in the muddy sediments, 5.8 to 15.6 percent by dry weight, and is particularly notable in samples taken from the Fox River area and along the north-south axis of the bay. Organic carbon generally decreases with increasing grain size of the sediment.

The sandy muds are transition sediments in areas apparently undergoing deposition. Depending on the clay contents, they can be classified as either sands or muds. The same areas occur along the western edge of the bay in a strip two to three miles wide and predominate in the northern third of the bay. The sands are characterized as well sorted, quartzose, and medium to fine in size. Coarser sands are found near shore.

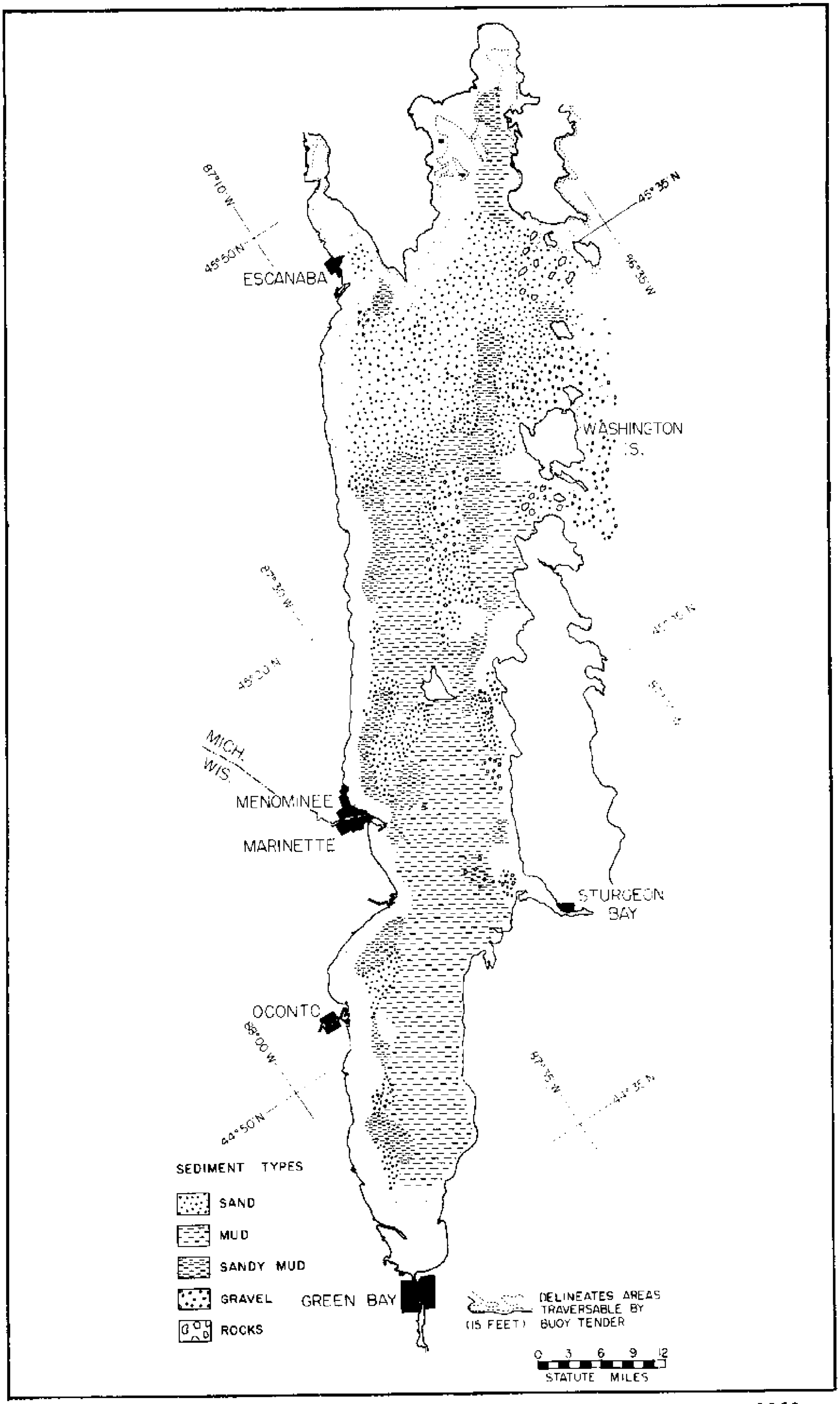


Figure 4. Surface Sediments of Green Bay. From Moore & Meyer, 1969.

Moore and Meyer found that the few rocky patches of the bay floor all occur along the northeastern shore. Rock fragments in these areas are geologically similar to the bedrock of the Door Peninsula. The fragments are primarily dolomite and sandstone with some metamorphic and granitic pieces. They are usually three to six inches in diameter and often stained by manganese. Amidst the rocky areas Moore and Meyer also found well-consolidated glacial clays or tills which appear to be resticted to these rocky sections.

The U.S. Army Corps of Engineers maintains access to the Port of Green Bay by a 25-foot channel which begins about three miles (4.8 km) NNE of the entrance light, opposite the Little Suamico River. In excavating this channel, the Corps found a hard clay silt layer 16 feet (4.8 m) below the present lake bottom. At approximately 23 to 60 feet depth, (7.0 to 18.2 m) another softer silty clay occurs (Soil Testing Services of Wisconsin, Inc., 1972).

Detailed sediment studies of the extreme lower bay, done as part of the thermal plume investigation of the J. P. Pulliam Power Plant, revealed a seasonal distribution of silts and sands inside Long Tail Point. Finer materials, such as silts and clays, tend to be deposited in near-shore areas during the ice-covered winter months. When the bay is ice-free, the shallows are freed of fine materials as the strong wind-driven mixing processes drive them to deeper water. The coarser, reworked shoreline sediments move bayward during the summer (Wisconsin Public Service Corporation, 1974).

The more common relationship of sediments--coarse materials in shallow waters and finer depositions in deep waters--does not appear to hold for the lower bay where the predominate force is the wind which resuspends and distributes sediments. The shallow bay water is readily set in motion, resulting in the lower bay's turbidity. <u>This turbidity would exist even in the absence of man-made loads of organic material and pollution-induced effects, such as eutophication</u> (WPSC, 1974). Figures 5a and 5b show the sand-silt shift of sediment distribution between January and March 1973.

c. Mineral Resources

Sand, copper and manganese appear to be the major mineral resources in Green Bay. None of these are currently exploited, however.

Sand in Green Bay is abundant, clean, and well sorted. A band three or four miles wide and over 40 miles in length along the west shore is accessible to hydraulic mining and could be commercially exploited as a local resource.

Two small areas of the bay, one about six miles east of Marinette and the other in midbay half-way between Marinette and Escanaba, show copper enrichment up to 2 percent of the sediment by weight. These deposits have no economic potential at this time, but their occurrence has not been explained (Moore and Meyer , 1969).

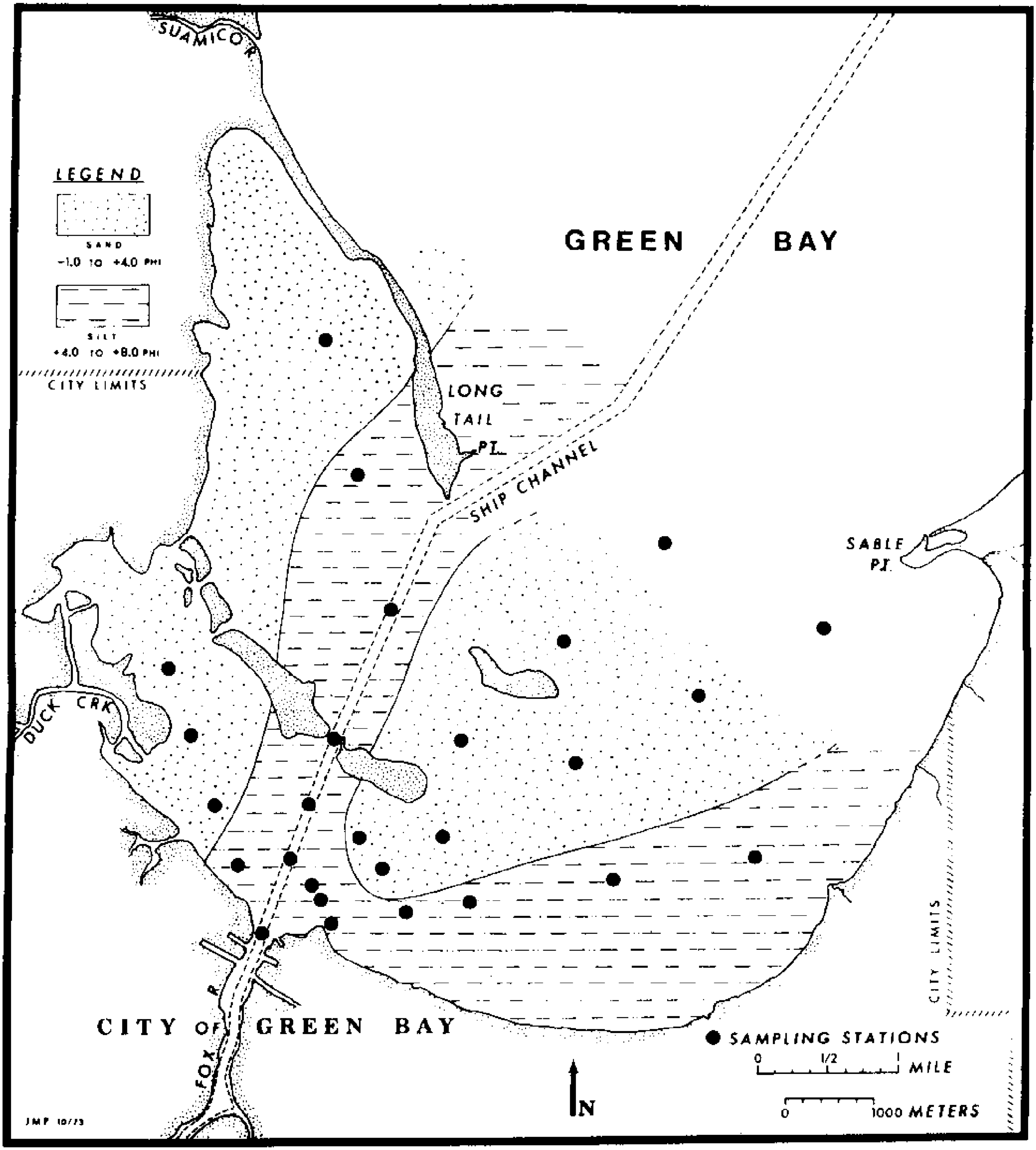


Figure 5a - Surface Sediment Distribution, January 1973. Compare with March distribution shown in Figure 5b. From Wisconsin Public Service Corporation, 1974.

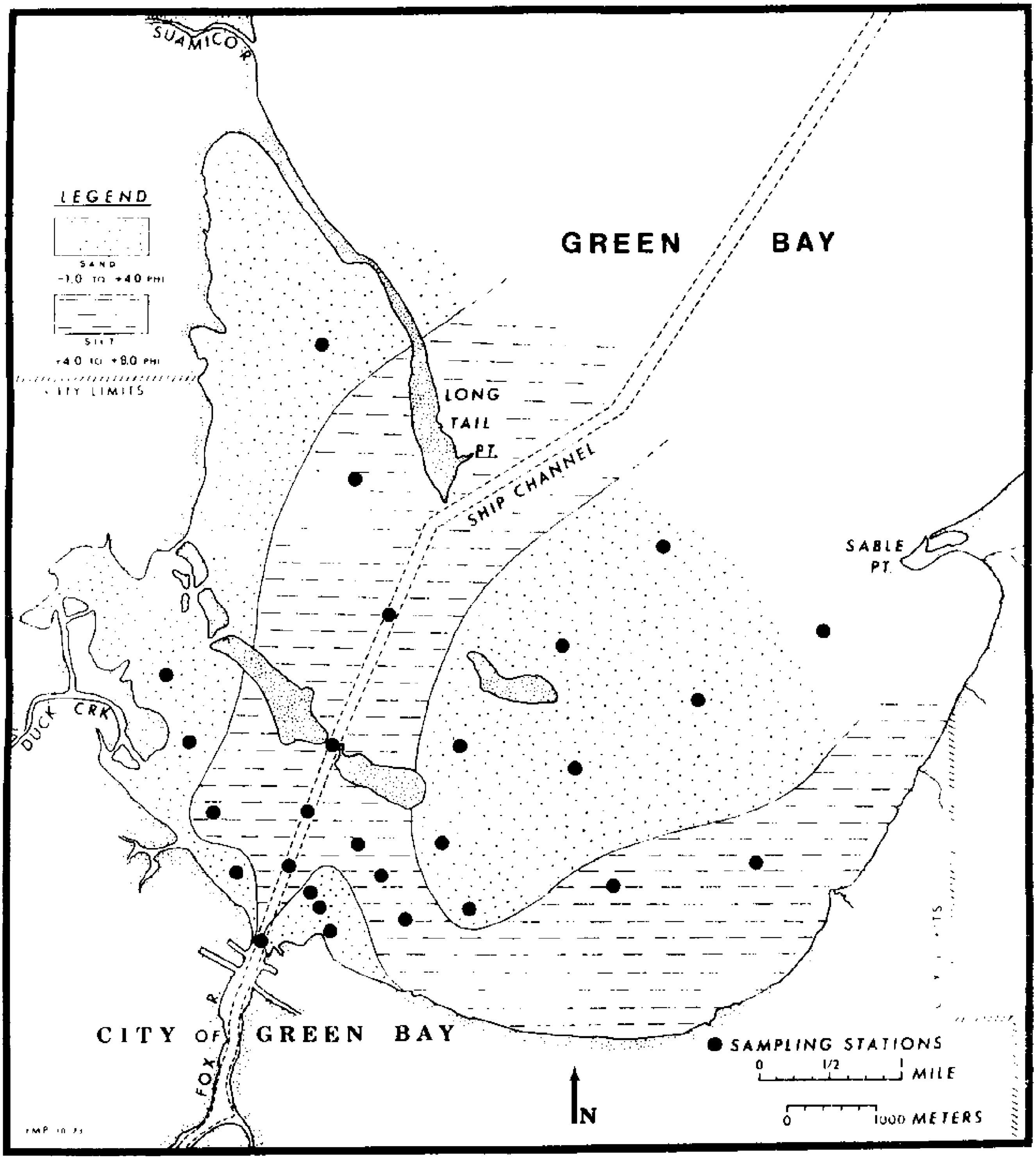


Figure 5b - Surface Sedimentation Distribution, March 1973. Compare with January distribution shown in Figure 5a. From Wisconsin Public Service Corporation, 1974.

The Moore and Meyer sediment survey (1969) revealed what appeared to be major ferro-manganese deposits in large areas of the bay. The pellets ranged from 1 to 7 mm in diameter, with the majority in the 4-6 mm range. The B-B sized pellets are of two general types: rounded and aggregate. Moore et al. (1973) explored the fine structure of the nodules using an electron probe. The rounded form contained a smaller proportion by weight of manganese than the aggregate shape. About half the pellets have a central quartz or felspar grain nucleus. The pellets form a highly reflective acoustical surface and are usually associated with sands or muddy sands. No pellet deposits were found in association with the fine muds in the southern portion of the bay. The deposits are almost always in water more than 40 feet (12 m) deep.

Based on over 700 core and dredge samples and over 1000 miles of seismic profiles, Moore et al. (1973) delineated the extent of the Green Bay deposits (Figure 6). The area of the bay covered by greater than 10 percent by volume of manganese is 233 square miles (373 km^2). Using an average depth of 4 inches (10 cm) the volume of the deposits is over two million cubic feet (7.46 x $10^6 m^3$). The average density is 2.39 gm/cm^3 and the total reserves are 4,540,000 metric tons of manganese and 12,200,000 metric tons of iron.

Detailed analysis of the Green Bay manganese deposits continued through August 1972. The deposits have a relatively low percentage of manganese, less than half of other fresh-water deposits. There is a corresponding higher percentage of iron. Unlike marine deposits, fresh-water nodules (including Green Bay's) are noticeably lacking in economically important trace elements such as cobalt, nickel, and copper.

How the manganese nodules were formed is presently unknown, but several theories have been advanced. The most promising one is that manganese that is placed in solution by the chemically-reducing, oxygen-deficient environment of the southern bay becomes accreted as pellets in the well-oxygenated waters of the northern bay (Moore and Meyer, 1968). The pellets cannot be more than 3,000 to 4,500 years old, as this is the age of the bay at current water level (Moore et al., 1973).

Elemental analysis of the Green Bay deep-water sediments was done by Callender (1972) to aid in the determination of manganese nodule origins. He felt the prime geochemical process in nodule formation was discrete concretion in oxidizing sediments. His analysis showed that arsenic, barium and nickel enrichment occurred in these sediments.

Moore et al. (1973) suggest three possible economic uses of the Green Bay manganese deposits:

(1) as elemental manganese. Present foreign sources are less expensive and adequate, but the Green Bay deposits can act as a reserve.

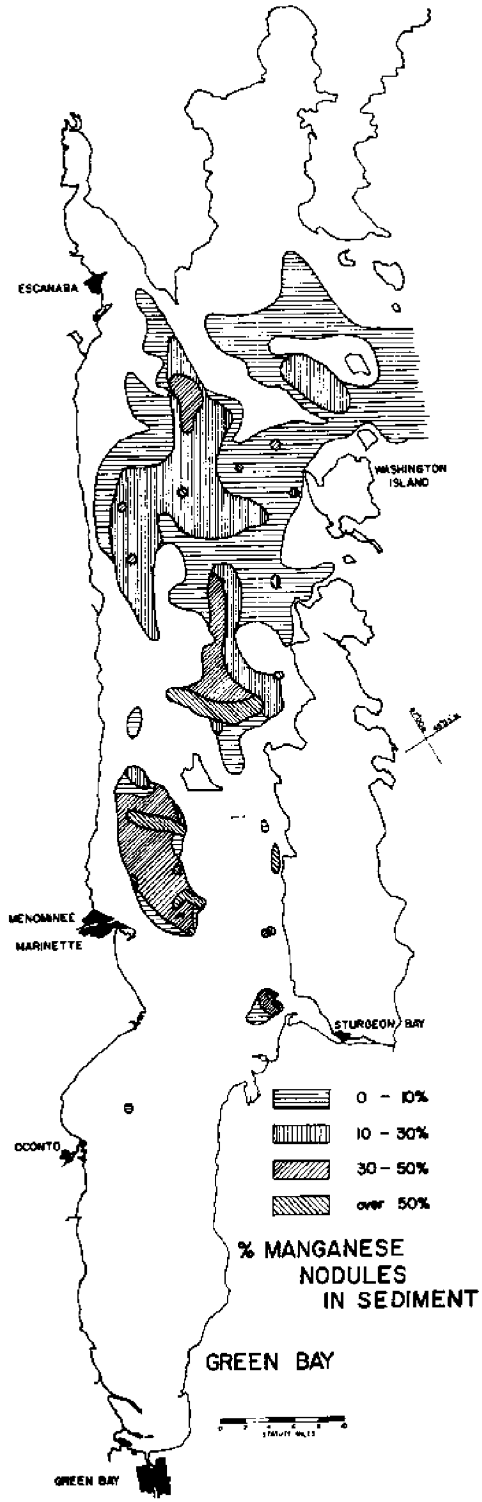
(2) as anti-pollution filters for automobile exhaust. The nodules have over 200 ml of surface area per dry gram, and the authors estimated they could be produced in packages for 10¢ per pound.

(3) as catalysts in industrial operations.

FIGURE 6 -

Distribution of Manganese Nodules

From Moore et al., 1973



The authors stress the legal complexities of Green Bay manganese exploration and exploitation, particularly the complex environmental effects of such an industry, and recommend early state action to meet industrial and public protection needs.

d. Bathymetry

In 1968, Moore and Meyer were able to map all depths greater than 15 feet (4.5 m) in Green Bay (Figure 7). The exception was a complex area off the Oconto River. The survey was made using 2 sonic transducers, a trans-receiver and an oscilloscope. Soundings were taken with a short sonic pulse of high power. The depths recorded were accurate to 0.5 foot (16.8 cm).

By using procedures similar or identical to earlier Corps of Engineers' U.S. Lake Survey procedures, Moore and Meyer were able to compare their 1968 survey results with those of the 1943 (southern bay) and 1950 (northern bay) surveys. The significant and surprising results of the 1968 survey showed that the southern bay had undergone a marked decrease in depth during the 18-year period since 1950. A specific decrease of 4 feet (1.2 m) was noted for many areas, and a decrease of more than 2 feet (0.6 m) was noted throughout the basin (Figure 8). Depth contours showed a marked northward displacement of contour lines in the lower bay. This rapid decrease in depth is not totally unexpected in light of the high sediment loads of the Fox, Oconto, and Menominee Rivers. The Fox-Wolf River Basin is approximately 6,250 square miles, and it is estimated that each square mile contributes 40 tons of sediment to the bay each year (Moore and Meyer, 1969). The Oconto-Peshgito-Menominee Basins comprise approximately 43,000 square miles and are estimated to contribute 20 tons per square mile per year to the bay.

Moore et al. (1973) suggest that the rapid deposition of muds, in particular muds with high levels of sewage, wood chips, organics, and trace elements such as chromium, copper and zinc, is a result of an anomalous situation in the bay that will be discussed under the circulation section.

1.3 WATER MOVEMENT

a. Mass Characteristics

Although the same major water movements in Green Bay have been noted since the area was first explored, only within the past 20 years have these movements been defined and quantified. Green Bay, as an arm of Lake Michigan, has approximately the same average water level as the Lake—about 580 feet (176m) above New York mean sea level. Since 1860, when the U.S. Army Corps of Engineers began keeping records, the water level has varied 6.6 feet (2 m) from the extreme high (1886) to the extreme low (1964). These water level fluctuations are usually due to long-term cyclic variations. Seasonal low water usually occurs in January, with higher levels occurring in June (Schraufnagel, 1966).

FIGURE 7 PRELIMINARY
BATHYMETRIC MAP
GREEN BAY, LAKE MICHIGAN

1968 DATA UNIVERSITY OF WISCONSIN
FROM
HIGH RESOLUTION PROFILE DATA
CONTOUR INTERVAL .0025 SEC = 6 FT
DATUM = 576.8 FT
FROM
LAKE SURVEY CHART # 703
DATA OF 1950 & 1943
CONTOUR INTERVAL 6 FT
DATUM = 576.9 FT

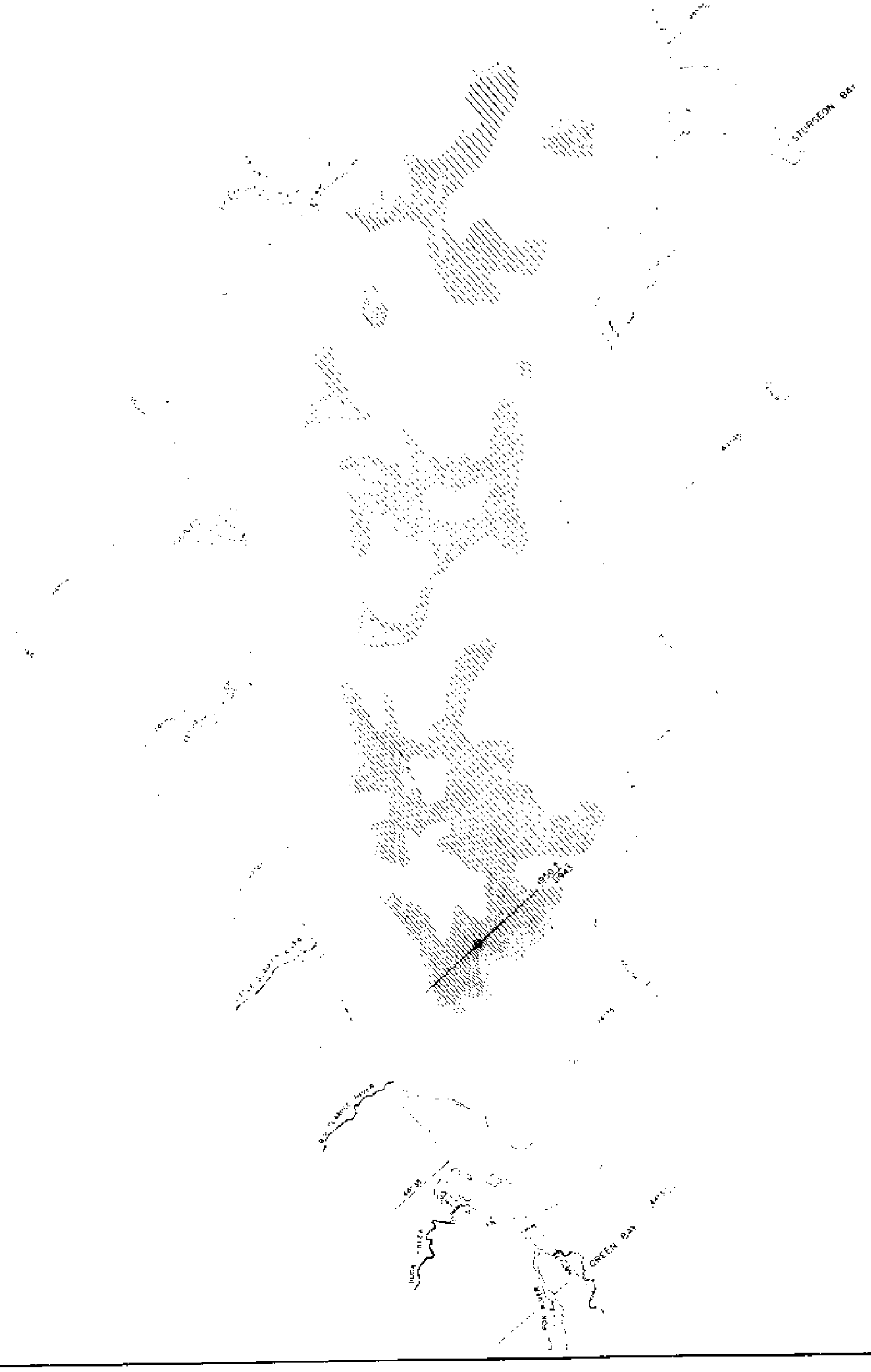
From Moore & Meyer, 1969

FIGURE 8 DIFFERENCES 1968 - 1950 or 1943
BATHEMETRY

SOURCES 1968 UNIV of WIS
1950-1943 LAKE SURVEY

1968 greater than 4 feet shallower
1968 greater than 2 feet shallower
· ENTRANCE LIGHT

From Moore & Meyer, 1969



The current water level of 580 feet (176 m) above New York mean sea level is a dramatic reversal of the level prevailing a decade ago. It has been suggested that this is one effect of a climatic change toward wetter conditions (Knox, 1974). The U.S. Army Corps of Engineers expects water levels to rive even higher before they subside (personal communication).

Shorter term variations in water levels, covering a span of several days or less, have received much attention. These seiches, as the fluctuations are called, occur in naturally existing basins which have normal periods of oscillation in which water moves from one side to the other. The elongated shape of the bay and the location of its major water source at the head of the bay make it ideal for water movement research. Harrington (1895), Scott et al. (1957), Johnson (1960, 1962, 1963), Saylor (1964) and Mortimer (1965) have investigated the existence and influence of seiches on Lake Michigan and Green Bay.

Seiche movement is influenced by winds, currents and atmospheric pressure. Weather conditions may completely damp out or greatly exaggerate a seiche. In Green Bay, seiches are most observable in tributary streams where there is an increase in water level and reversal of stream flow. Scott et al. (1957) observed that the usual change in water levels is 1 foot per day (0.3 m) or much less, but on November 18-19, 1957, the East River had a change of 4.7 feet (1.33m) in 17 hours. Schraufnagel (1966) cites stream flow reversal in the East River 6 miles (9.6 km) up from the mouth of the Fox. Three to four cycles or reversals were observed per day. The flow rate in the lower section of the East River was 374 c.f.s. or 168,000 gallons per minute going upstream, as measured with dye tracers. Schraufnagel (1966) reported reversal in the Fox River as far as De Pere Dam, 7 miles (11 km) upstream. Flow at the river mouth was measured to be over 280 cubic meters per secomd (10,000 c.f.s.) going upstream.

The general circulation in the lower two-thirds of Green Bay, as shown in Figure 9, was summarized in Schraufnagel (1966) in a report to the Governor's Conference on Lake Michigan Pollution. The report stated:

> The Fox is the Bay's dominant stream . . . . The usual pattern of currents . . . is for the Fox River flow to continue in a northerly direction into the Bay for about 10 miles (15 km), then veer easterly and follow the east side of the Bay from the Red Banks-Dykesville area to Little Sturgeon Bay. Indications are that this forms part of a counter-clockwise route going in a southerly direction on the west side of the Bay near Pensaukee and swinging east and north. The southern part of the curve lies in the vicinity of the two outer channel lights. The Bay's bottom contours, shoals, spits and points appear to substantiate the counter-clockwise circulation. Eventually all of the water that flows into Green Bay flows out into Lake Michigan, but these flows are probably small in comparison to the water movements associated with currents and seiches [within the Bay].

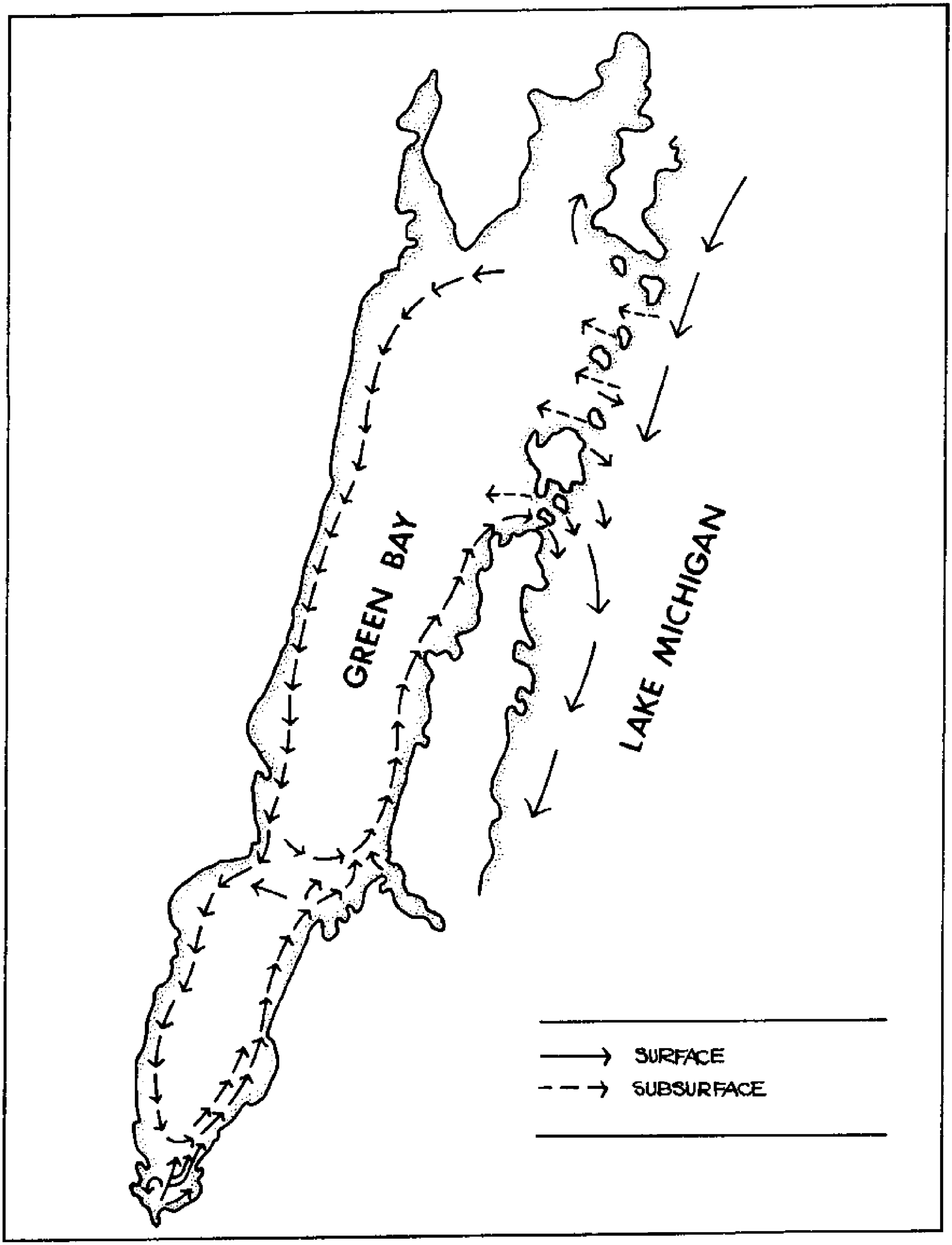


Figure 9. Generalized Map of Currents in Green Bay

Sometimes there are pockets in the lower end of the Bay which permit little water movement in and out. This is particularly true in the bay beach area (Bay Beach Park) lying in the section east of the line between Grassy Island and Point Sable and in the area west of the shipping channel and south of Long Tail Point. The latter area is relatively shallow and is fed by Duck Creek. There is a shoal between Point Sable and Grassy Island which generally cuts off circulation from the main portion of the Bay. On occasion the waters of the Fox, although somewhat concentrated along the shipping channel, appear to be fairly well dispersed across the lower 10 or 15 miles of the Bay (16 to 24 km).

Water quality measurements and density considerations indicate that in the summer months the warmer river waters overflow the lake waters, but in the winter the river waters tend to follow the bottom for some distance before diffusing into the main body of water.

Although this general description has been modified by recent work, it is generally correct and at the time represented a good inference based on only fragmentary information. The general conformation of the bay means that it can be regarded as a lake separate from Lake Michigan. And, as a shallow bay, it is more responsive to temperature changes than Lake Michigan. It cools faster in the fall and becomes thermally stratified earlier in the summer. The southern part of the bay is more than 7° C warmer than the northern part and 12° C warmer than deep lake water (U.S. Federal Water Pollution Control Administration, 1966).

The openings between the bay and the rest of Lake Michigan are restricted to the Washington Island area on the northeast side and the Sturgeon Bay Canal midway up the Door County Peninsula. Ayers et al. (1954) in drift bottle studies found eastward surface currents in the passages between islands off the Door County Peninsula. The dominant Lake Michigan circulation is counter-clockwise, so outflowing Green Bay water is carried south as it leaves the bay.

Lake Michigan water enters the bay in two ways:

First, in the late fall and in early spring, water driven by easterly winds enters the bay in large quantities. The prevailing winds from May to August are south to southwest and shift to west to southwest until early fall. Late fall and winter winds are west through northwest. Only in the early spring and late fall do winds drive sufficient amounts of Lake Michigan water into the bay to cause moderate flooding in the lower bay and inundating of shoreline homes. In 1973, flooding was particularly severe in the lower bay and there was extensive damage to the City of Green Bay.

The second and more important source of inflow from Lake Michigan to the bay is the diurnal (daily), year-round influx from the seiche movements. Ahrnsbrak and Ragotskie (1970) developed a one-dimensional circulation model comparing observed diffusivities to those predicted by seiche activity and used this model to test the analogy of a fresh water bay to a marine estuary developed earlier (Ragotzkie, Ahrnsbrak, Synowiec, 1969). The analogy was acknowledged to be much simplified, since the true marine estuary is marked by salinity gradients and much stranger tidal changes.

For the study, it was assumed that the concentration field of Fox River waters is in a steady state situation, that it is a conservative variable and one that can be traced as it changes, and that the Fox River is the only source of tracer materials (pollutants) into Green Bay. The latter assumption can be justified by reference to Table 2.

Table 2. Average Discharge Rates of Water, Suspended Solids and Chlorides for Four Rivers Entering the Southern End of Green Bay

River, Location	Discharge Rate ($m^3 \cdot day^{-1}$)	Suspended Solids Concentration ($mg \cdot l^{-1}$)	Suspended Solids Net Transport ($kg \cdot day^{-1}$)	Chlorides Concentration ($mg \cdot l^{-1}$)	Chlorides Net Transport ($kg \cdot day^{-1}$)
OCONTO at Oconto	2.35×10^6	9.8	2.3×10^4	6.7	1.57×10^4
MENOMINEE at Marinette	8.96×10^6	5.3	4.75×10^4	1.4	1.25×10^4
PESHTITO at Peshtigo	2.25×10^6	5.6	1.26×10^4	0.6	1.35×10^4
FOX at Green Bay	11.3×10^6	17.1	19.3×10^4	12.3	13.9×10^4

from Ahrnsbrak and Ragotzkie, 1970.

Based on its net flow of water and pollution load, the Fox River is almost an order of magnitude larger than the sum of the other three major rivers emptying into the bay. The Fox has been regarded as the major pollution source in earlier works by Schraufnagel (1968) and Schnider (1968). The assumption is validated for purposes of this study if the residence time of Fox River water in the lower bay is greater than the data collection period of the study. The residence time calculated by R. F. Modlin (per. comm. in Ahrnsbrak and Ragotzkie, 1970) was 40 days. The summer sampling took just over 60 days, creating some slight possibility for error. The assumption that river water was a conservative variable is checked by calculating evaporation-preciiptation rates for the bay. These changes, maximum P-E = 0.5 percent, were considered to be negligible. Some of the conclusions of the investigations were as follows:

(1) Polluted Fox River water concentrates south of Long Tail Point, comprising 50 to 80 percent by volume.

(2) A tongue of Fox River water, 30-40 percent by volume, extends northward on the east side of the bay under the influence of southerly winds but is absent with northerly winds.

(3) The concentration of Fox River water decreases to 25 percent at a distance of 9.4 to 15.7 miles (15 to 25 km) from the river mouth and decreases rapidly northward from there.

(4) Diffusivities in the lower section of the bay were approximately 0.25×10^6 cm^2/sec. This rapidly changed to 1.0×10^6 at 9.4 miles (15 km). Beyond 9.5 miles (15 km) the change was gradual —3×10^6 at 18.7 miles (30 km and 0.7×10^6 cm^2/sec at 59 miles (95 km).

(5) Long Tail Point seems to act as a barrier to mixing, although there is rapid diffusion of river water to the north of the point.

Ahrnsbrak (1971) conducted a winter survey of water movement based on electrical conductivity of the water. He found that under the ice, the influence of Fox River water extended over a larger area than during the summer and that the region's maximum conductivity gradient was displaced northward. Figure 10 compares summer and winter conductivity gradients. A distinct surface tongue of river water is identifiable to 15 miles (25 km) at which point it sinks as a distinct water mass and continues north. Where in summer the transverse gradient at 15 miles is not discernable or randomly distributed on the east, middle or west of the bay, the winter tongue produced a distinct transverse gradient from east to west, 15 miles from the river mouth. This is thought to be caused by retarded mixing under the winter ice. The ice dampens seiche movement and protects the water from wind effects. The one-dimensional model and estuary analogy of Ahrnsbrak and Ragotzkie (1970) were found to work well for the summer situation but are not applicable to winter conditions (Ahrnsbrak, 1971).

The work of Modlin and Beeton (1970) was done at the same time as that of Ahrnsbrak and Ragotzkie (1970) and is generally consistent with it. The Modlin-Beeton study did not attempt to describe the physical mechanisms of mixing, as did the Ahrnsbrak-Ragotzkie study, but it did refine the water distribution pattern by using a more extensive and a tighter sampling pattern. As in the earlier studies, Fox River water was found to extend northward along the east side of the bay. The tongue extended 8.6 miles (14 km) north in July 1968 and 21 miles (34 km) north in August 1968, demonstrating the variability reported by Ahrnsbrak and Ragotzkie (1970). Sharp transverse gradients were found as far north as the Pensaukee River over 18.7 miles (30 km) from the mouth of the Fox. The western two-thirds of the bay above Long Tail Point was primarily lake water which circulated in a counter-clockwise manner between Oconto and Long Tail Point. This is the general pattern described by Schraufnagel (1966) and Schraufnagel et al., (1968), with the exception that the water did not initially go north 9.4 miles (15 km) before veering east, as described by Schraufnagel (1966), but veered east earlier, particularly during summer months.

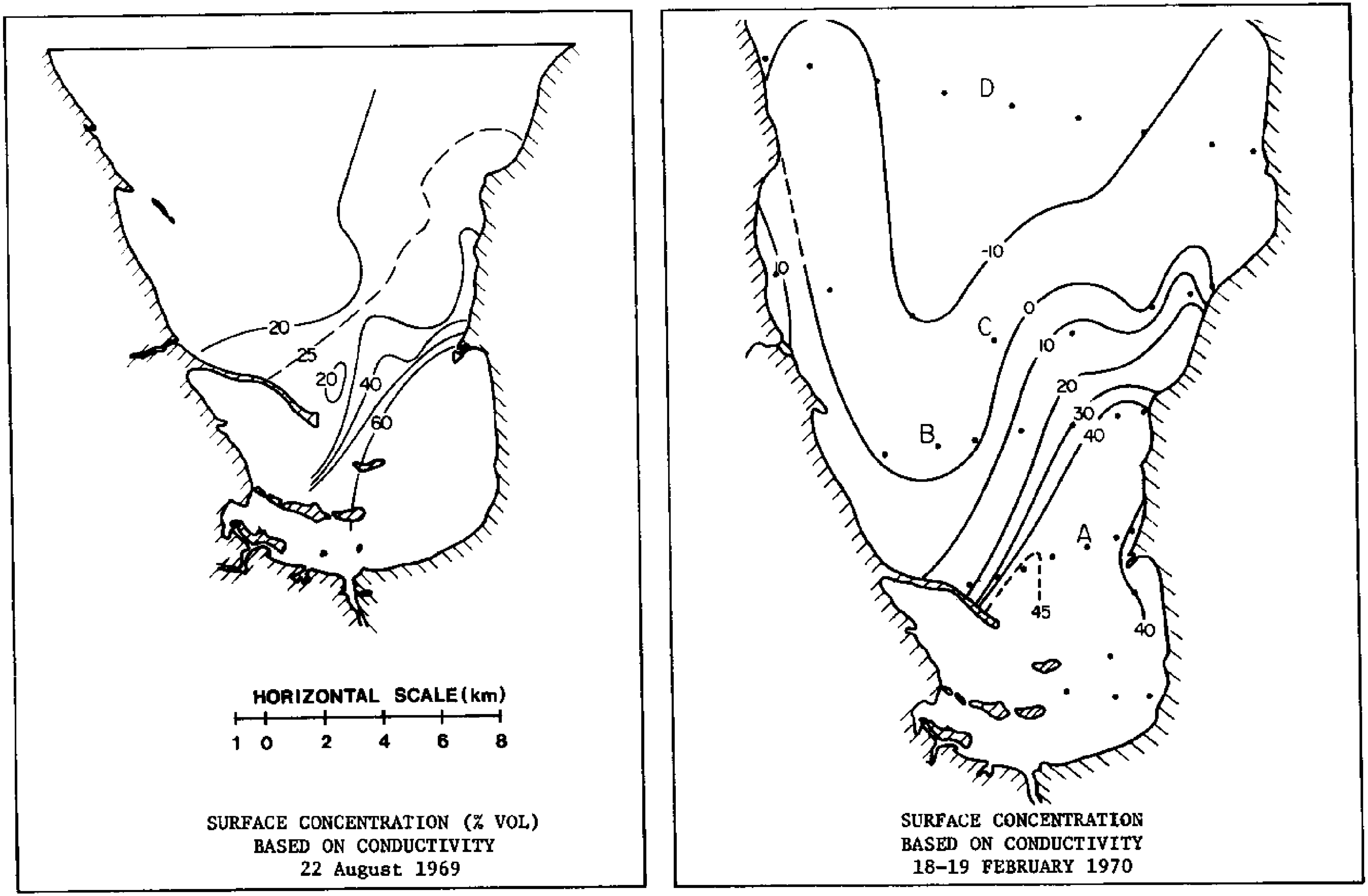


Figure 10. Surface Concentrations (percent volume) of Fox River Water in the Head of Green Bay, Based on Electrical Conductivity. February 1970 readings taken under the ice (Ahrnsbrak, 1970). August 1969 data from Ahrnsbrak & Ragstzkie (1971).

Modlin and Beeton (1970) reported water inside Long Tail Point to be 70 percent river water. This is within the 50-80 percent found by Ahrnsbrak and Ragotzkie (1970). Green Bay flushing rates (the length of time required for one day's accumulation of river water to move through Green Bay or a portion of the Green Bay) were also noted. They were calculated as 160 days with a river discharge average of 5,913,120 m^3/day in August 1969; and 107 days with a discharge of over 8,000,000 m^3/day (Modlin and Beeton, 1970). This latter figure is close to the 60-year mean discharge of 9,000,000 m^3/day, although discharges four times this have been recorded (Knowles et al., 1964). Flushing time decreases with increasing river discharge.

Transport volumes were also calculated, and a transport ratio of 128.00 was found at a point between the tip of the Door Peninsula and Cedar Creek, Michigan. The lakeward transport at this point was 1,130 m^3/day. The transport ratio is equal to the total water volume over the river water volume moving lakeward. The lower the ratio, the greater the exchange. The lakeward transport which indicates the magnitude of the inflowing countercurrent from the lake was something over 1,000 m^3/day in August 1969.

Light penetration studies using Secchi discs to measure Fox River water movement were done by Schraufnagel et al., (1968) and Sager (1971). The steepest gradient occurred within the first 8 to 11 miles (5 to 7 km) from the mouth of the Fox. Inside Long Tail Point plankton concentrations, suspended solids in the river water, and wind-driven, resuspended sediments contribute to the low transparency. Schraufnagel et al., (1968) found that Secchi disc readings could be taken from depths of only 1.5 to 2 feet (0.45 to 0.60 m) at the river mouth. However, light penetration improved at increasing distances from the river mouth. At the entrance light, 10.6 miles (17 km) from the river, readings were taken at 5 to 6 feet (1.5 to 1.8 m) depths. Discs were also read at 9 to 10 feet (2.7 to 3.0 m) depths off Sturgeon Bay, 35 miles (56 km) distant; and at depths of 16 feet (4.9 m) off Washington Island, 70 miles (112 km) distant. Suspended solids at the mouth of the Fox have been measured at 7 to 20 mg/1 (Sager, 1971). Moore et al., (1973) found that the surface sediment distribution conforms to the observed current pattern. Additional evidence for the northwest-flowing east shore current comes from the distribution patterns of benthos (Howmiller and Beeton, 1970); dissolved oxygen (Schraufnagel et al., 1968); and plankton (J. E. Gannon, per. comm. in Modlin and Beeton, 1970).

In a 1971 survey, F. J. Bates (in Howmiller and Beeton eds., 1973) investigated the light penetration in Green Bay. He measured penetration directly as a percentage of surface light by using a modified photometer (Table 3). Extinction coefficients were calculated, and all light was found to penetrate deeper in Lake Michigan than in Green Bay. Blue and green light attenuated faster than red light in Green Bay. Light penetration results confirmed the existence of Green Bay's two distinct water masses, lake water on the west shore and Fox River water on the east. The results are tabulated in Table 3. Bates raised some questions as to the accuracy of the photometer used in this study, since there was no time for standardization testing prior to the cruise. The results should be used accordingly.

In the same 1971 survey, Howmiller (in Howmiller and Beeton eds., 1973) described the surface currents from drift bottle experiments. Seven bottles were released at each of 15 stations in southern Green Bay. Forty-seven percent

Table 3. Light Penetration in Green Bay

Station*	Date	Time	Sky	Sea	Secchi Disc	Light	Extinction Coefficient (K)		
Green Bay		CST			Metered	Total light	Blue/340-480 mu	Green/470-580 mu	Red/570 mu
22	7/12/71	0820-0835	Clear	2-3 ft waves	2	0.98	--	--	--
20	7/12/71	1120-1140	Overcast	1-2 ft waves	1.3	1.8	3.4	1.7	1.4
15	7/12/71	0915-0930	Clear Lt. haze on horizon	3-4 ft waves	1.6	1.1	2.9	--	--
14	7/12/71	1210-1230	Overcast	1-ft waves	1.5	4.5	--	3.7	0.90
11	7/12/71	1330-1350	Overcast	1-ft waves	0.5	1.2	3.4	1.6	1.4

From F. J. Bates, in Howmiller and Beeton eds., 1973.

* See Appendix, Figure 77, for station locations.

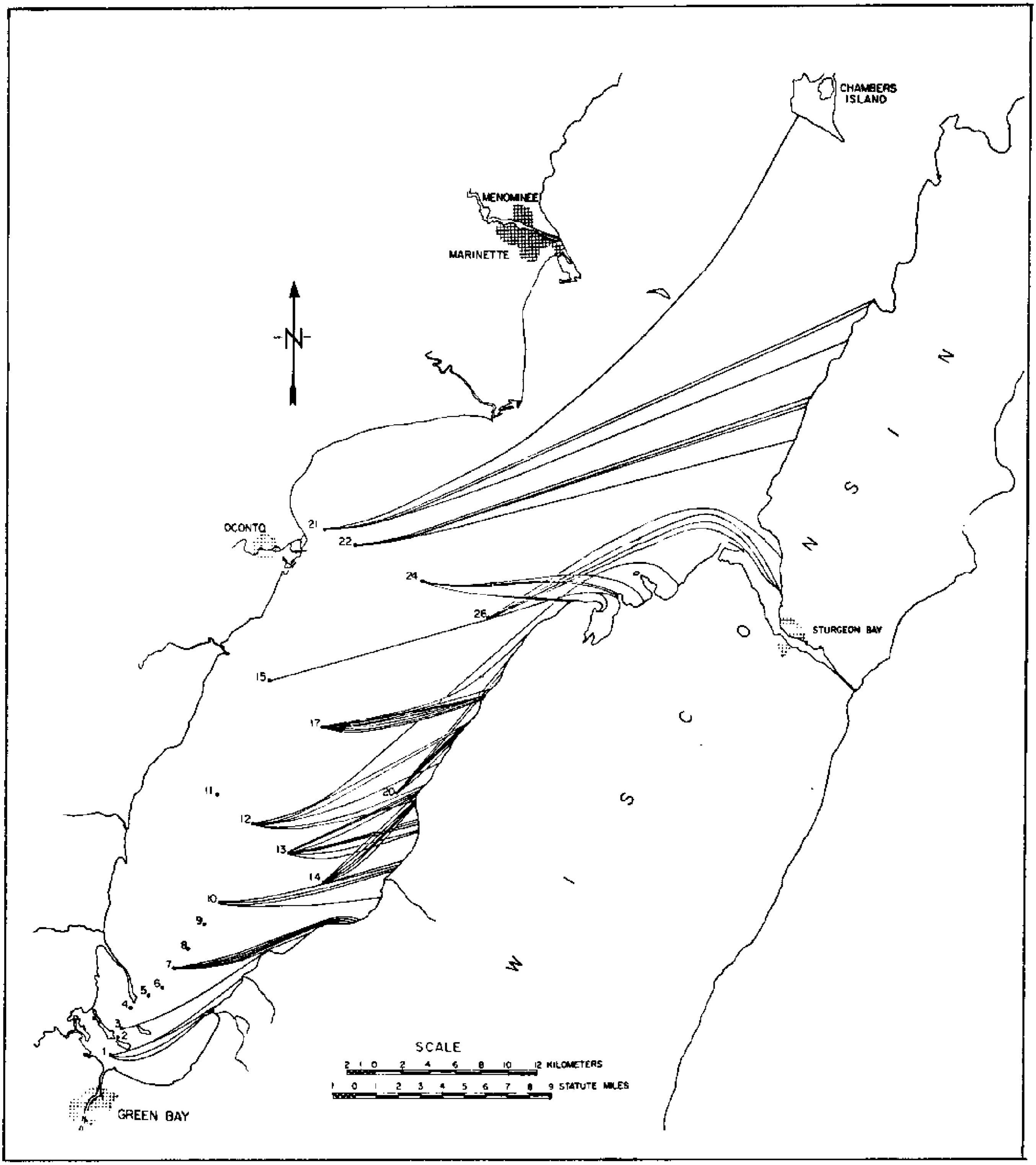


Figure 11. Green Bay, Showing Stations at Which Drift Bottles were Released and Presumed Paths of Recovered Bottles. From Howmiller, in Howmiller and Beeton, eds., 1973.

were recovered within ten days of release. The presumed paths of the bottles are given in Figure 11. The uniform northeastward movement is at variance with the described current regime. However, strong winds from the south prevailed during the experimental period and indicate their importance to surface drift in a shallow bay with generally weak or moderate currents. Total bottle returns were 72 percent. Howmiller surmises that if bottles released on the west of the bay were influenced by a south flowing current, the bottles could be lost in the west shore marshes.

The role of the Sturgeon Bay Ship Canal on the water transfer between Green Bay and Lake Michigan is unknown. It is known, however, that two years after the canal opened in 1882, a new commercial whitefish ground had established itself off the mouth of Sturgeon Bay. Fishing had been poor in this area previously. Within three years after the canal was completed, the yellow perch fishery in the lower bay increased greatly in importance. These biological changes suggest some major change in water conditions after the opening of the canal.

The Sturgeon Bay Canal is currently a localized pollution source, and its polluted condition may damp out any benefits Green Bay might receive from this narrow connector to Lake Michigan. However, the influence of the canal on lower Green Bay is a potentially fruitful area for investigation.

2. CHEMICAL CHARACTERISTICS OF GREEN BAY

2.1 OXYGEN

Dissolved oxygen levels are commonly used indicators of water quality. Low oxygen levels often indicate that a system is overloaded with organic debris which is demanding large amounts of oxygen for its decomposition. When this demand causes low oxygen levels to persist over long periods of time, a lake's fauna undergoes significant changes. Most noticeable is the replacement of commercial and game fish species by rough fish, and the disappearance from the water column and the sediments of a diverse community of invertebrates. In their place appear large numbers of a few tolerant species of worms and midges.

The organic materials exerting oxygen demand on a water body can be coarse and easily visible, such as twigs and leaves, or they can be fine particulate or even colloidal matter. These materials can enter the lake in watershed runoff or in effluent discharges, or they can be manufactured within the lake itself as green plant material. (Not uncommonly, excessive nutrient enrichment of a lake will stimulate an explosive growth of algae and aquatic plants. As these plants die back and decompose, a critical drop in oxygen levels may occur.)

In lower Green Bay, dissolved oxygen levels and water quality in general are determined primarily by the character of the Fox River outflow. The distributional pattern of dissolved oxygen in the bay corresponds to the distribution of Fox River water in the bay. In summer months the Fox River is a source of oxygen-depleted water to the bay. The high biochemical oxygen demand (BOD) of wastes discharged by industries and municipalities, and their rapid depletion of the river's dissolved oxygen, cause oxygen levels to approach and sometimes reach zero milligrams per liter in warm weather.

Critically depressed oxygen levels are usually found in warmer months along the entire length of the lower Fox River. They extend from Appleton to the river mouth and out into the bay for a distance of about 3 miles (5 km). In July and August dissolved oxygen levels of less than 2.0 milligrams per liter (mg/l) are often found in the lower bay opposite the river mouth and inside Grassy Island. An anoxic zone which develops each summer in this area has been fatal to carp carried through the water in nets by commercial fishermen (Dan Olson, per. comm.). In warmer months, oxygen conditions improve from the lower bay to the upper bay as winds and currents re-aerate the water and allow wastes to be assimilated and diluted. Within the lower bay, oxygen levels are higher on the west shore than on the eastern shore. This is because the east shore is more directly affected by river flow and the elevated temperatures of the Pulliam Power Plant's discharge waters.

The re-aeration occurring outside Long Tail Point and Point Sable is rapid and summer oxygen values may reach 8 to 10 mg/l north of these points. In the fall, prior to ice formation, dissolved oxygen levels in both the river and the lower bay increase due to wind action and to lower temperatures which slow down the decomposition process. By the time that ice forms, the oxygen deficit of summer has been completely reversed. However, with the coming of ice, atmospheric re-aeration is cut off and the heavily oxygen laden waters of the Fox River (8 to 10 mg/l) become the major oxygen source to the bay. With cold temperatures, the waste decomposition rate decreases and there is less immediate demand on the river's oxygen supply. This slow-down in the assimilation of wastes by the river causes the assimilation process to be carried out into the bay.

Thus, the zone of minimum oxygen levels is pushed bayward from the inner bay to the middle bay. Along the eastern shore, the zone of depressed oxygen levels may extend up to 31 miles (50 km) north from the mouth of the river. Oxygen content generally decreases bayward from the river mouth to a point where the zone of minimum oxygen level is reached (2 mg/l or less). Northward from that point, levels again increase. The location of this zone of maximum deficit varies, but is generally somewhere outside Point Sable.

Dissolved oxygen concentrations in Green Bay have been examined in the following major surveys: Wisconsin State Committee on Water Pollution (1939), Surber and Cooley (1952), Balch et al., (1956), Schraufnagel et al., (1968), Sager (1971), Hausmann (1973), and Wisconsin Public Service Corporation (1974).

The Pulliam Power Plant study of 1973 (Wisconsin Public Service Corporation, 1974) conducted a concentrated survey of the lower bay's oxygen condition in order to determine the effect of the plant's outfall plume on the lower bay. The sampling stations were numerous and well distributed within the lower bay. (See Figure 78.) In general the Pulliam survey findings agreed with those of earlier studies: the highest oxygen values in the inner bay were found in February under the ice and lowest values in July and August near the river mouth (Tables 4 and 5).

Table 4. Summary of Analysis for Dissolved Oxygen (mg/l O_2) in Lower Green Bay and Vicinity of Pullium Plant (1973)

Sampling Date	Maximum	Station Number [a]	Minimum	Station Number [a]	Average
January 25*	11.8	93	6.2	10	8.7
February 28**	17.9	26	8.7	10	11.5
March 28	15.5	21	10.5	2	12.1
April 24	15.6	27	9.1	2	10.9
May 24	9.7	9	6.0	2	7.9
June 19	7.4	25	3.0	14	5.2
July 17	8.5	27	2.9	13	5.4
August 15	14.3	7	0.0	2	6.3
September 10	13.7	21	5.6	93	9.4
October 7	11.8	5	4.6	15	8.8
November 9	12.9	26	6.7	92	11.0
December 20***	10.8	92	9.8	99	10.4

*Only stations 1, 3, 4, 5, 6, 8, 10, 13, 18, 19, 20, 21, 25, 26, 27, 90, 92, 93, 99 sampled.

**Only stations 3, 4, 5, 6, 10, 12, 13, 20, 21, 25, 26, 27, 92, 93, 99 sampled.

***Only stations 92, 93, 99 sampled.

[a] See Appendix, Figure 78, for station locations.

From Wisconsin Public Service Corporation, 1974

The Pulliam Study also examined oxygen levels in the Fox River. One of the primary aims of the study was to examine oxygen levels in the plant's two river water intakes (one located on the river and one located at the mouth of the river), and the oxygen concentrations in the outfall located between the two intakes. The investigators found that the river water underwent little change in oxygen concentration while passing through the power plant. Those changes that were noted were thought to have insignificant effects on the over-all oxygen concentrations of the bay. However, their routine monitoring of the river mouth revealed large daily variations in its oxygen level during the warmer months. For example, on August 15, 1973, there was a range of 14.3 mg/l between the day's highest and lowest oxygen values (Table 4).

Table 5. Summary of Analysis for Percent Oxygen Saturation in Lower Green Bay and Vicinity of Pullium Plant (1973)

Sampling Date	Maximum	Station Number [a]	Minimum	Station Number [a]
January 25*	89.8	99	43.8	10
February 28**	131.0	26	60.6	10
March 28	126.0	19	83.2	2
April 24	147.0	27	78.1	9
May 24	96.0	9	59.1	2
June 19	83.1	25	34.2	17
July 17	78.2	7	23.3	22
August 15	158.0	7	0.0	2
September 10	135.0	27	61.6	15
October 7	109.0	5	44.4	15
November 9	92.4	8	57.0	92
December 20***	92.5	99	73.7	92

*Only stations 1, 3, 4, 5, 6, 8, 10, 13, 18, 19, 20, 21, 25, 26, 27, 90, 92, 93, 99 sampled.

**Only stations 3, 4, 5, 6, 10, 12, 13, 20, 21, 25, 26, 27, 92, 93, 99 sampled.

***Only stations 92, 93, 99 sampled.

[a] See Appendix, Figure 78, for station locations.

From Wisconsin Public Service Corporation, 1974.

The location, duration and severity of low oxygen levels may reflect a change in the health of the bay's ecosystem. Blach et al., (1956) found the deficient zone on the eastern shore 15 miles farther north in 1956 than it had been the previous year. And, while Schraufnagel et al., (1968) found that summer dissolved oxygen concentrations in 1966 were similar to those found in 1938 (Wisconsin State Committee on Water Pollution, 1939), they also felt that winter oxygen concentrations were lower in the bay in 1966 than in 1939. Nevertheless, too many factors influence oxygen levels to use oxygen as a prime indicator of health. For example, the generally low water conditions in the bay in 1966 may have been responsible for the worsened oxygen levels observed at that time. Similarly, the 1971 surveys of Hausmann (1973) and Sager (1971) indicate relatively higher dissolved oxygen concentrations in the lower bay than previous surveys (Figure 12 and Table 6). But 1971's water levels were also much higher than in 1966 and high oxygen values are thought to be at least a partial result of these high water conditions.

The Pulliam Power Plant study also showed that the oxygen patterns within the river and bay are highly variable. The large specific variation in oxygen levels that the investigators found reflects both the high productivity rates of phytoplankton and the high organic decomposition rates of Fox River wastes. But it also indicates the difficulty of generalizing about oxygen concentrations in a situation as complex as that which occurs within Long Tail Point. For clear evidence of the bay's health, other less variable parameters than oxygen are better indicators.

Table 6. Dissolved Oxygen Concentrations (mg/1)
(See Appendix, Figure 79, for station locations)

Stations	I	II	III	IV	V	VI	VII	VIII	IX
June 17	3.65	4.73	7.75	7.70	7.75	7.79	7.79		
June 24									
July 1	5.76	4.70	5.05	9.80	9.44	9.70	9.70	9.70	9.70
July 10	6.46	6.71	7.27	8.67	9.54	9.49	8.79	8.79	8.99
July 22		5.50	6.59	5.96	8.59	8.13	8.20	7.73	7.60
August 5	4.00	3.35	8.78	8.49	8.60	8.31	7.92	7.68	7.60
August 12	2.72	5.54	10.45	9.51	9.64	9.24	9.23	9.14	9.89
August 21	0.20	5.37	8.27	10.61	9.58	8.73	8.95	8.94	9.14

From Sager, 1971

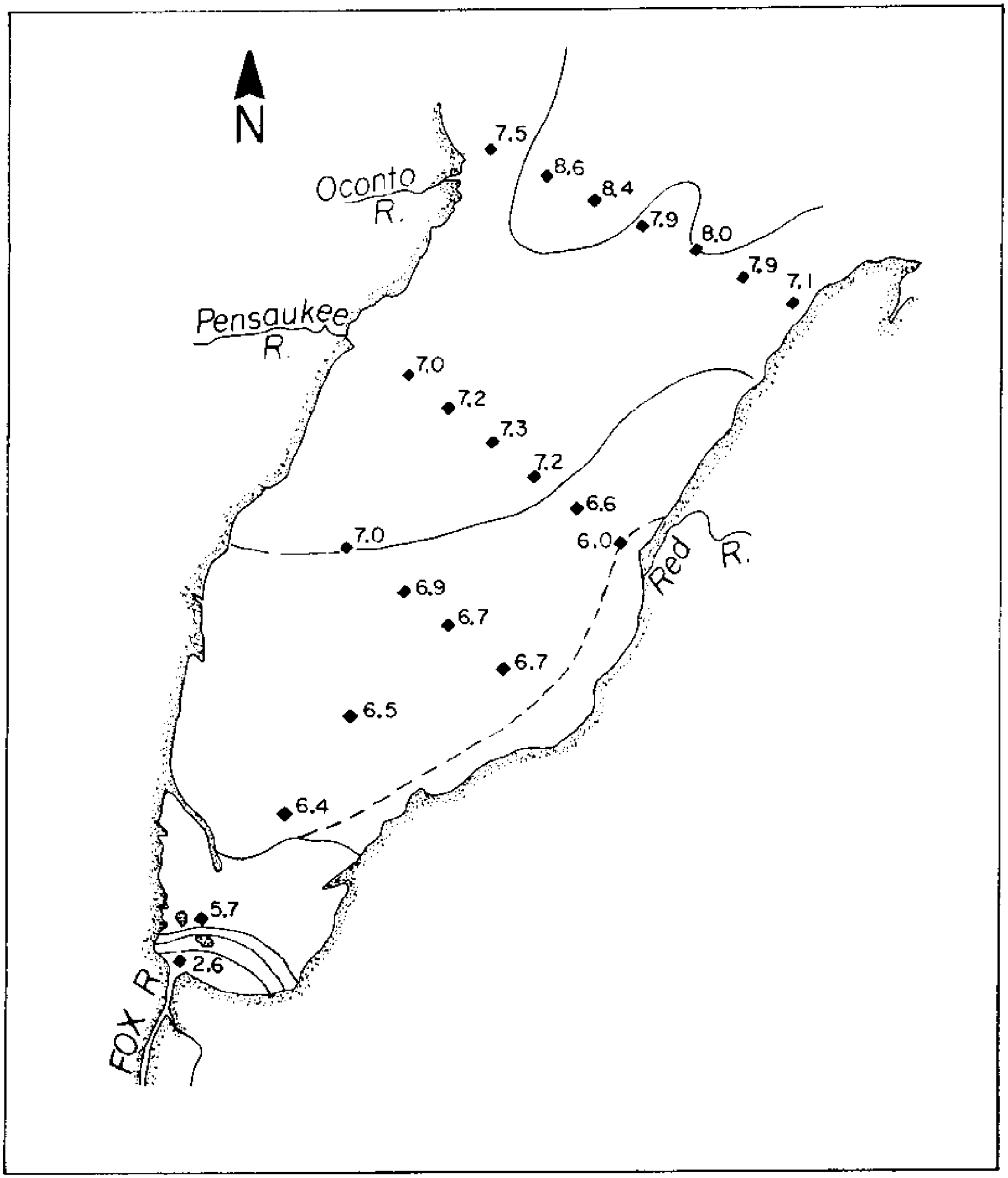


Figure 12. Green Bay, Lake Michigan, Showing Dissolved Oxygen Concentration (ppm) at 2 m depth on 13 July 1971. From Hausmann, 1973.

2.2 NUTRIENTS

a. Phosphorus Concentrations

In 1971 the summer algae bloom in Green Bay extended 15 miles from the mouth of the Fox River; in 1972, 20 miles; in 1973, the bloom extended 30 miles up the eastern shore to Sawyer Harbor just below Sturgeon Bay. In 1974 the bloom did not go as far up the bay as in previous years. This was possibly due to dilution of critical plant nutrients by heavy precipitation and accompanying high water levels in the bay. During high water periods, the extent of the bloom may decrease while the incoming nutrient load remains the same. Under these conditions, the perception that conditions are improving can be misleading. Nevertheless, the unpleasant effects of these blooms as they rot and wash ashore have been well described in local newspapers in Green Bay and reported by Napoli (1973). This most obvious evidence of the eutrophication of lower Green Bay has been a matter of great concern among bayshore communities.

The immediate cause of the blooms is nutrient enrichment of the bay, particularly phosphate enrichment. Although phosphate enters the bay from a number of sources, several surveys have shown that it is most heavily concentrated near the mouth of the Fox River and decreases as one moves northward up the bay.

Schraufnagel (1968) in 1966 sampled the concentrations of orthophosphate and total phosphate along the length of the bay (Table 7); Sager and Wiersma (1972) sampled phosphorus loads to lower Green Bay from the Fox River in 1971 (Table 8, Figure 13); and Sridharan and Lee (1974) analyzed a year's worth of phosphorus data on lower Green Bay (Table 9). The data of the latter showed total phosphate concentrations of 0.13 to 0.70 mg/l (average 0.304 mg/l) south of Long Tail Point; and concentrations of 0.04 to 0.30 mg/l (average 0.108 mg/l) north of Long Tail Point. Vanderhoef et al., (1972.1973) showed that there was considerable variation in phosphorus concentrations in the bay from year to year. Soluble phosphate levels in lower Green Bay ranged from .003 to .055 mg/l in 1971 and from .035 to .081 mg/l in 1972. Rousar (1973) and Rousar and Beeton (1973) sampled surface concentrations of total phosphorus in the lower bay (Figure 14).

In 1973 the Pulliam Power Plant Study (Wisconsin Public Service Corporation, 1974) sampled 27 stations in the lower bay for water chemistry, including total phosphorus and orthophosphorus. Total phosphorus averaged 0.175 mg/l (Table 10a) and orthophosphorus averaged 0.028 mg/l over the 27 stations (Table 10b). Total phosphorus was generally evenly distributed over the lower end of the bay. However, orthophosphorus values were higher near the mouth of the Fox River during warmer months. The average values for orthophosphorus found in lower Green Bay are approximately 10 times those of Lake Michigan.

Total phosphorus did not appear to undergo change in the intake-outfall waters of the power plant. However, 25% of the orthophosphate values taken in January, April and December showed unexplained and significant elevations while passing through the plant.

Table 7. Phosphorus Concentrations From Green Bay - 1966 (in mg/liter)

Date	Miles from Mouth of Fox	Phosphorus as Sol.P	Tot.P	Color (s.µ.)	Date	Miles from Mouth of Fox	Phosphorus as Sol.P	Tot P	Color (s.µ.)
10/19/66S	1	.009	.150	50	8/18/66S	40	.011	.048	8
8/11/66S	4	.024	.032		8/18/66B	40	.014	.038	5
8/ 9/66S	10	.012	.088	20	10/21/66S	40	.009	.052	
8/ 9/66B	10	.015	.122	22	8/19/66S	60	.018	.028	
10/19/66S	10	.01	.06	9	10/21/66S	60	.016	.03	6
8/ 9/66S	20	.004	.058		8/19/66S	70	.01	.02	
8/ 9/66S	20	.012	.066	8	8/19/66B	70	.01	.024	
10/19/66B	20	.012	.064	7	10/21/66S	70	.014	.044	
8/10/66S	30	.007	.074	8	5/18/66S	Michigan	.014	.016	
8/10/66B	30	.014	.06	8	8/18/66B	Michigan	.008	.022	
10/19/66S	30	.009	.064		10/21/66S	Michigan	.016	.032	

From Schraufnagel et al., 1968

Table 8. Average Loadings to Green Bay From the Fox River at Station 10.* Values in lb./day

	Average Flow (cfs)[2]	Ortho PO_4	Total P as PO_4
June-August	2,330	363	7,670
September-November	3,220	1,730	8,580
December-February	4,010	5,190	7,120
March-May	6,600	5,040	29,500
Annual Average	4,040	3,080	13,200

Multiply by 0.4536 to convert loadings to kg/day.
Multiply ft^3/sec by 0.02832 to convert flow to m^3/sec.

From Sager and Wiersma, 1972

*See Appendix, Figure 79, for station locations.

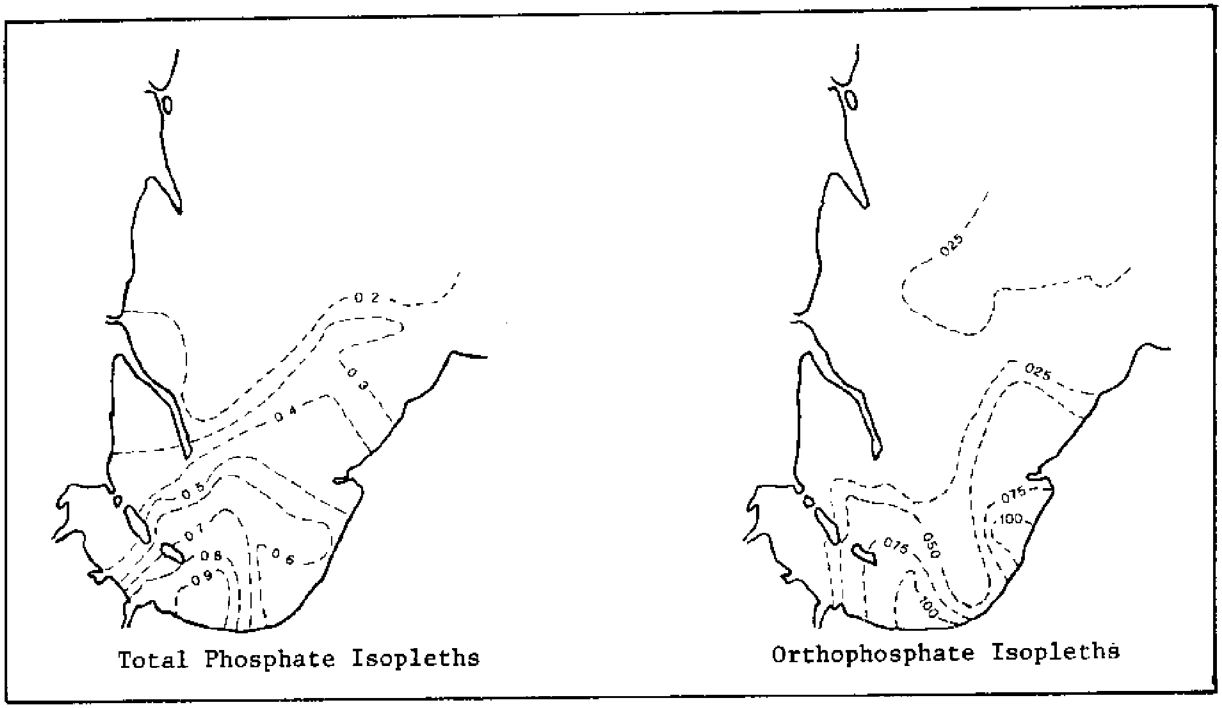


Figure 13 - Phosphate Levels (mg/1) in Lower Green Bay
(July 20, 1971).
From Sager and Wiersma, 1972.

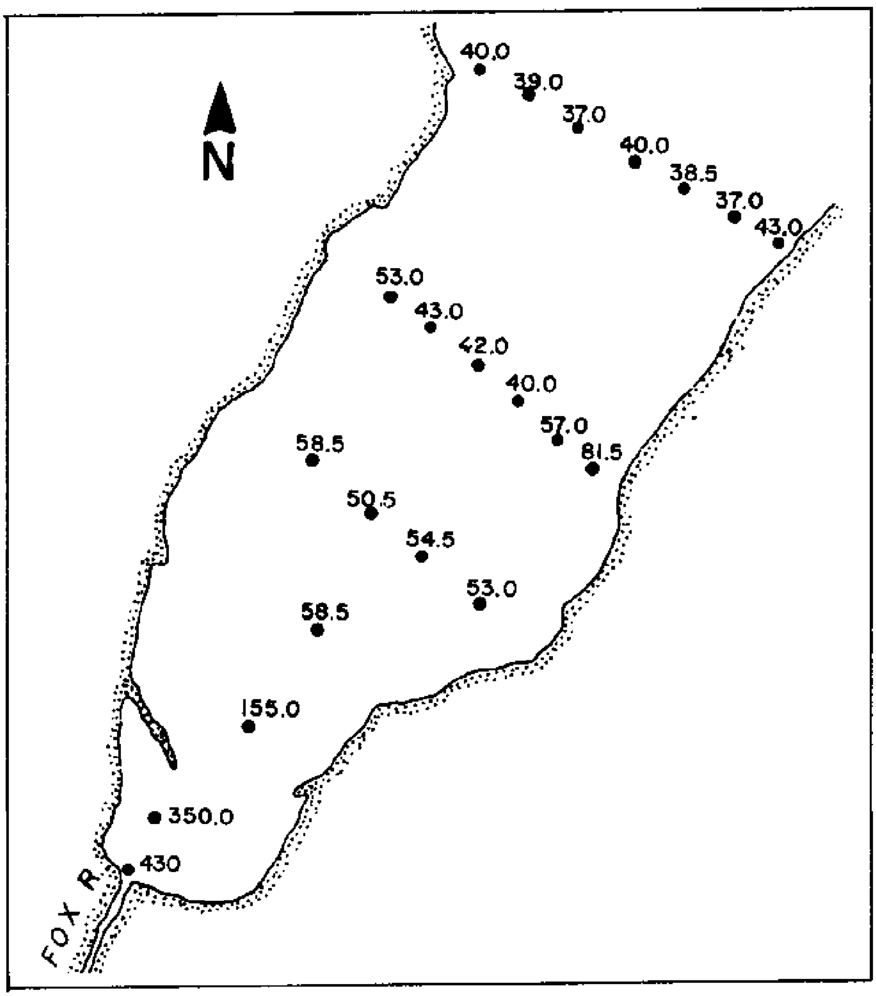


Figure 14. Surface Concentrations of Total Phosphorus in µg /liter from 2 m depth.

From Rousar and Beeton, 1973.

Table 9. Phosphorus in Lower Green Bay (October 1968 - October 1969)

	South of Long Tail Point				North of Long Tail Point			
	Number of Samples	Range	Mean	Std. Deviation	Number of Samples	Range	Mean	Std Deviation
pH	28	7.0-8.0	7.96	0.33	12	7.4-8.6	8.5	0.3
Soluble ortho P (mg/l)	21	0.01-0.11	0.050	0.030	12	0.01-0.06	0.015	0.007
Soluble organic P (mg/l)*	21	0.00-0.15	0.050	0.050	8	0.01-0.03	0.029	0.020
Total P (mg/l)	28	0.13-0.70	0.304	0.110	14	0.04-0.30	0.108	0.080

From: Sridharan and Lee, 1974.

Table 10a. Summary of Analysis of Total Phosphorus (mg p/l) in Lower Green Bay and Vicinity of Pullium Plant (1973)

(See Appendix, Figure 78 for station locations)

Sampling Date	Maximum	Station Number	Minimum	Station Number	Average
January 25[a]	0.36	6	0.15	1,90	0.26
February 28[b]	0.24	26	0.06	27	
March 28	0.29	22	0.07	26	0.14
April 24	0.27	1	0.06	24	0.18
May 24	0.21	16	0.04	25	0.09
June 19	0.46	1	0.09	23	0.18
July 17	0.47	16	0.08	24	0.21
August 15	0.31	1	0.09	25,26	0.19
September 10	0.50	18	0.06	26	0.22
October 7	0.14	99	0.03	26	0.08
November 9	0.33	14	0.03	4,24,26	0.10
December 20[c]	0.08	99	0.07	92,93	0.07

[a] Only stations 1,3,4,5,6,8,10,13,18,19,20,21,25,26,27,90,92,93,99 sampled.
[b] Only stations 3,4,5,6,10,12,13,20,21,25,26,27,92,93,99 sampled.
[c] Only stations 92,93,99 sampled.

From Wisconsin Public Service Corporation (1974)

Table 10b. Summary of Analysis of Orthophosphate (mg p/l) in Lower Green Bay and Vicinity of Pullium Plant (1973)

(See Appendix, Figure 78, for station locations)

Sampling Date	Maximum	Station Number	Minimum	Station Number	Average
January 25[a]	0.16	26	0.03	4	0.09
February 28[b]	0.08	26	0.01	3,6,20,21,25	
*March 28	---	--	---	---	---
April 24	0.04	4	0.01	1,5,9,13,16, 21,22,24,27	0.01
May 24	0.08	20	0.01	1,3,12,14,15, 90,99	0.04
June 19	0.06	3,6	0.01	14,24,25,92	0.03
July 17	0.10	5	< 0.01	15,90	0.03
August 15	0.05	6,10	< 0.01	15	0.01
September 10	0.06	25	0.01	11,17,20,24 27,99	0.03
October 7	0.05	23	< 0.01	6,17	0.01
November 9	0.04	99	0.01	24,27	0.01
December 20[c]	0.03	99	0.01	92,93	0.02

* All stations < 0.01

a Only stations 1,3,4,5,6,8,10,13,18,19,20,21,25,26,27,90,92,93,99 sampled.
b Only stations 3,4,5,6,10,12,13,20,21,25,26,27,92,93,99 sampled.
c Only stations 92,93,99 sampled.

From Wisconsin Public Service Corporation (1974)

b. Phosphorus Sources

There is no doubt that the nutrient loadings that come from the mouth of the Fox River are primarily responsible for the eutrophication of the lower bay. Sager (1971) showed that the Fox contributes 81% of the total 4,734,754 pounds (2,149,587 kg) of phosphorus that the bay receives each year (Table 11).

Sridharan and Lee (1974) and Sager and Wiersma (1972, 1975) described the annual phosphorus additions to Green Bay from various sectors of the Fox River watershed (Table 12). They showed that municipal and industrial wastes account for 1,515,000 pounds of phosphorus or 62.5% of the yearly total. Of this percentage, industrial plants contribute only a relatively small share. Although the Fox River has the heaviest concentration of pulp and paper mills in the world and does receive a heavy BOD burden from the mill wastes, the wastes are relatively nutrient poor. Consequently their phorphorus loads are less than those of adjacent municipalities. In 1971, 17 pulp and paper mills on the lower Fox contributed 1,078 pounds (488 kg) of phosphorus to the river per day. During the same period, 9 sewage plants on the same stretch of river contributed 2,094 pounds (949 kg) of phosphorus per day (Epstein et al., 1974). This was consistent with the findings of Sager and Wiersma (1972) who analyzed the municipal component of the Fox River phosphorus load from October 1970 to September 1971. They found that the Green Bay Metropolitan Sewage Treatment Plant located at the mouth of the Fox contributed 1,417 pounds (641 kg) per day, over half the daily average of orthophosphate, and 2,094 pounds (949 kg) of total phosphorus per day.

But even without the additions of industrial and municipal effluents along the river's lower stretch, the Fox River is already heavily laden with nutrients and is in a degraded state as it leaves Lake Winnebago (Sager and Wiersma, 1972). The average annual phosphorus load entering the Fox from Lake Winnebago is 6,620 pounds (3,012 kg) per day. This load originates largely in urban and rural runoff from the Lake Winnebago watershed.

Sager and Wiersma (1972, 1975) also showed that rural runoff was a major source of phosphorus in the lower Fox watershed especially during the spring (see discussion pp.219-221). In 1966 a U.S. Department of Health, Education and Welfare study showed that the total amount of phosphorus from land runoff in the Green Bay area was 1,167,000 pounds (531,000 kg) pounds of total phosphorus per year. According to Sridharan and Lee (1974), over one-third of the total phosphorus coming into the lower Fox River is from rural runoff (Table 12). Although pollution abatement requirements have been set for municipal and industrial point source polluters, rural runoff remains a major uncontrolled source and will continue to be a problem.

Table 11. Estimated Phosphorus Input into Green Bay Through its Tributaries

River	Flow (cfs)	Concentrations (mg p/1)	lbs p/yr
Fox[a]	Average daily loading of total phosphorus 10,484 lbs/day		3,826,660
Oconto[b]	569	0.15	168,264
Peshtigo[b]	825	0.09	146,124
Menominee[b]	3,096	0.08	487,434
Escanaba[b]	900	0.06	106,272
	TOTAL - lbs P/yr		4,734,754

1 cfs = 0.02832 m^3
1 lb = .4536 kg

a Sager (1971)
b U.S. Department of Interior, Federal Water Control Administration (1966)

From Epstein et al. 1974

Table 12. Estimated Phosphorus Sources for the Fox-Wolf River

Source	Annual Contribution (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 on Lake-River Surfaces	12,700	0.5
Groundwater	----	----
TOTAL	2,445,500	100.0

1 lb = .4536 kg

From Sridharan and Lee (1974)

c. Phosphorus Cycle

Once phosphorus enters the bay or river, it becomes part of the aquatic phosphorus cycle. This cycle is seasonal and can be summarized as follows:

With the high waters of spring, large volumes of phosphorus are washed into the lower Fox River and lower Green Bay system. These spring phosphorus loads come primarily from turbulent mixing of sediments, suspended solids, plant material that decomposed the previous fall and farm land runoff. During this period, orthophosphate and total phosphorus tend to increase in the Fox in the downstream direction.

As spring progresses to summer, there is a decrease in the orthophosphate concentration as one moves downstream along the Fox. This decrease can be ascribed to sedimentation loss and increased assimilation of phosphorus by rooted aquatic plants and phytoplankton within the river.

During the summer months under low or anoxic conditions, the sediments continue to release large amounts of phosphorus to the water system. Sridharan and Lee (1974) demonstrated that the amount of phosphorus released to the system decreased with distance from the mouth of the Fox River and was associated with the type of sediment in which the phosphorus was contained. Those sediments with a high percent of solids, that is more sand-sized particles, had lower orthophosphate release than silty sediments with high organic content. High phosphate release was also found to be correlated with high concentrations of iron in the sediment.

Jayne and Lee (1971) modeled the phosphate transport between the sediment water interface in the lower Fox River and Green Bay. They estimated the orthophophorus release in the summer months within Long Tail Point to be on the order of 20-30 percent of the total phosphorus transported out of the area. In addition, there may be some release of phosphorus in the southeast corner of the bay where the sediments are regularly stirred by turbulence. Beyond Long Tail Point, sediments absorbed rather than released orthophophate during the summer months.

In the fall as temperatures drop and algae decrease in productivity and begin decomposing, large amounts of phosphorus are released from their tissues. Sager and Wiersma (1972) found that 61% of the phosphorus released by the algal die-off in Lake Winnebago was in the form of orthophosphate. During the subsequent quiescent winter period, much of the autumn release of phosphorus becomes incorporated into the sediments behind dams on the Fox River. The remainder proceeds downstream and becomes part of the lower Green Bay system. During the winter period, the release of phosphorus from the sediments is much reduced from a summer period due to the oxygen-laden water conditions.

The role of phosphorus as a stimulant of plant growth in lower Green Bay has been studied by Allen (1966), Sager (1971), Sridharan and Lee (1974), Vanderhoef et al., (1972, 1973), and Epstein et al., (1974). These studies indicate that algae growth in the lower bay normally would be phosphorus limited if it were not for the massive man-caused inputs of phosphorus.

With the spring influx of phosphorus, Green Bay undergoes a major spring diatom bloom. As summer progresses, this diatom bloom changes to a bloom of blue-green algae. Vanderhoef et al. (1972, 1973) investigated specific populations of blue-green algae, particularly Aphanizomenon and Anabaena. They concluded that it was possible that the phosphorus-stimulated diatom bloom declined as available phosphorus declined. By the time the population reached a lower level where phosphorus was no longer limiting, nitrogen had become limiting. The phytoplankton population then became dominated by nitrogen-fixing blue-green algae which had a competitive advantage over the diatoms.

Sager in 1971 also investigated a bloom of Aphanizomenon flos-aquae. The bloom was associated with a major influx of phosphate-rich water from the Fox River in late July. Sager found an inverse relationship between the high presence of orthophosphate and the luxury uptake (uptake in excess of immediate needs) of the orthophosphate by bay water algal populations. As distance from the mouth of the Fox increased and orthophosphorus levels decreased, the rate of luxury consumption of bay water algae increased. It is unknown if all algae exhibit luxury uptake and under what conditions luxury uptake of phosphorus may occur. It is clear from the past studies, however, that phosphorus is the major limiting factor of algae growth within the bay.

d. Nitrogen Concentrations

Nitrogen ranks alongside phosphorus as a critical nutrient for plant growth and as a stimulant of eutrophic productivity when present in excess amounts. Nitrogen occurs in three primary forms in the aquatic system: ammonia, nitrite and nitrate.

Ammonia is the main nitrogen product released from decomposing plant and animal proteins. The presence of ammonia in the water column generally indicates some degree of oxygen deficit. In the presence of oxygen, ammonia is readily converted to nitrite and then to nitrate.

Nitrate is the form of nitrogen most readily available and most rapidly utilized by plants. Its low levels in lower Green Bay indicate that it is being assimilated at a high rate by organisms and that the bay is in an advanced state of eutrophication. For example, Allen (1966) in his investigation of nitrates in Green Bay, found that levels were low and during some periods, i.e., September, were unmeasurable. In 1966 and 1967, Schraufnagel et al., (1968) continued the investigation of nutrients, particularly in the middle bay. Summer samples indicated less than 0.3 mg/1 total inorganic nitrogen (Table 13a). Ammonia concentrations were found to be highest in areas of algal blooms and high biological productivity, particularly within 10 miles of the river mouth. Kenny and McIntosh (1974) have indicated that ammonia may be incorporated into the sediments when ammonia concentrations in the water column are high. Conversely, ammonia is released from the sediments when ammonia levels in the water are low.

The investigations of Sager and Wiersma (1972) followed the average annual loadings of various forms of nitrogen into the Fox River and lower Green Bay from 1970 to 1971. Their results (Table 13b) showed that average annual loadings to the Fox River were 17,100 pounds per day (7,800 kg) for nitrate-nitrogen (NO_3-N) and 12,400 pounds per day (5,600 kg for ammonia nitrogen (NH_3-N).

Table 13a. Nitrogen Concentrations from Green Bay (1966) (in mg/liter)

Date	Miles from Mouth of Fox	T.O.	NH3	NO2	NO3	TION
10/19/66S	1	1.57	.46	.007	.2	(.667)
8/11/66S	4	.45	.11	.004	.08	(.194)
8/ 9/66S	10	.83	.12	.003	.08	(.203)
8/ 9/66B	10	1.01	.07	.004	.08	(.154)
10/19/66S	10	.39	.05	.002	.06	(.112)
8/ 9/66S	20	.38	.04	.002	.06	(.102)
8/ 9/66S	20	.62	.09	.003	.04	(.133)
10/19/66B	20	.63	.11	.002	.04	(.152)
8/10/66S	30	.50	.06	.002	.04	(.102)
8/10/66B	30	.42	.09	.002	.18	(.272)
10/19/66S	30	.36	.04	.008	.06	(.108)
8/18/66S	40	.39	.08	.005	.04	(.125)
8/18/66B	40	.26	.08	.002	.20	(.282)
10/21/66S	40	.29	.10	.01	.14	(.250)
8/19/66S	60	.25	.02	.004	.05	(.074)
10/21/66S	60	.11	.09	.004	.14	(.234)
8/19/66S	70	.26	.08	.004	.10	(.184)
8/19/66B	70	.24	.05	.008	.30	(.358)
10/21/66S	70	.14	.03	.003	.24	(.273)
5/18/66S	Michigan	.19	.02	.003	.14	(.163)
8/18/66B	Michigan	.22	.05	.003	.20	(.253)
10/21/66S	Michigan	.13	.04	.002	.24	(.282)

From Schraufnagel et al., 1968.

TABLE 13b

AVERAGE NITROGEN LOADINGS TO GREEN BAY
FROM FOX RIVER AT STATION 10.* VALUES IN lbs/day

	NO3-N	NH3-N
June-August	563	6,480
September-November	3,200	7,100
December-February	5,080	10,600
March-May	59,600	25,600
Annual Average	17,100	12,400

Multiply by 0.4536 to convert loadings to kg/day.
Multiply ft^3/sec by 0.02832 to convert flow to m^3/sec.

From Sager and Wiersma, 1972.

*See Appendix, Figure 79, for station locations.

In the Wisconsin Public Service Corporation Study (1974), the 27 stations in lower Green Bay were found to contain ammonia nitrogen that ranged from 0.01 to 2.10 mg/l nitrogen and averaged 0.32 mg/l nitrogen. Ammonia tended to decrease with distance from the mouth of the Fox River during the study. Significant ammonia levels were found in the lower Fox River above the power plant intakes.

Nitrate levels in the lower bay were generally found by Kenney and McIntosh (1974) to be low and averaged less than 0.5 mg/l nitrogen except during summer months when values fell near 0. These are similar to values found by Sager and Wiersma and are attributed to the assimilation by algae during warmer months. Nitrite levels in lower Green Bay and the Fox River were generally found to be high. Maximum concentration found was 0.04 mg/l nitrogen in June. All stations had detectable nitrite levels during the study in all months. Nitrite levels in the bay are positively correlated with ammonia levels.

The investigators felt that the rapid conversion of ammonia by micro-organisms resulted in the higher concentrations of nitrite in the bay. As in previous studies, organic nitrogen and ammonia were found to reach their peaks during summer months. Organic nitrogen levels range from 0.16 mg/l nitrogen in January to a maximum of 0.44 mg/l nitrogen in August. The highest values of organic nitrogen and ammonia were found near the mouth of the Fox River during warmer months. However, January values were highest at stations away from the mouth of the Fox as might be expected with the displacement of the oxygen minimum area bayward during the colder months.

e. Nitrogen Sources

Although yearly total input of nitrogen into the Fox River System was greater from Lake Winnebago than from municipal and industrial plants on the lower Fox River, the Fox River industries and sewage plants were the most significant source during the summer period and accounted for almost 75 percent of the total summer loading. There were significant seasonal changes in the levels of the various forms of nitrogen. Ammonia in particular is closely correlated with dissolved oxygen levels. During winter and early spring oxygen peaks, ammonia reaches its lowest point. During the summer, the effects of BOD loads entering the bay are compounded by high rates of biological production and ammonia reaches its greatest value. Conversely, while ammonia nitrogen was highest in the lower bay during the summer, it is at its point of lowest discharge from Lake Winnebago because of in-place utilization and assimilation by the algae of the lake. This cycle reverses in the autumn. With decomposing algae and organic matter releasing ammonia nitrogen, the ammonia flow from Lake Winnebago into the Fox River increases.

Runoff is an important non-point source of inorganic nitrogen. It is most significant during spring when there is heavy rainfall and snowmelt. An equally significant non-point source is the nitrogen-fixing blue-green algae of the bay. Vanderhoef et al., (1972, 1973) investigated this source of nitrogen and concluded that 2.9×10^5 kg of NH_4^+ - N was produced in a major portion of lower Green Bay between June 14 and August 17, 1972. This is similar to the 7.5×10^5 kg (NH_4 + NO_3^-) -N discharged into the bay by the Fox River during this same period. In 1973 the Department of Natural Resources in data presented by Epstein et al., (1974) showed significantely

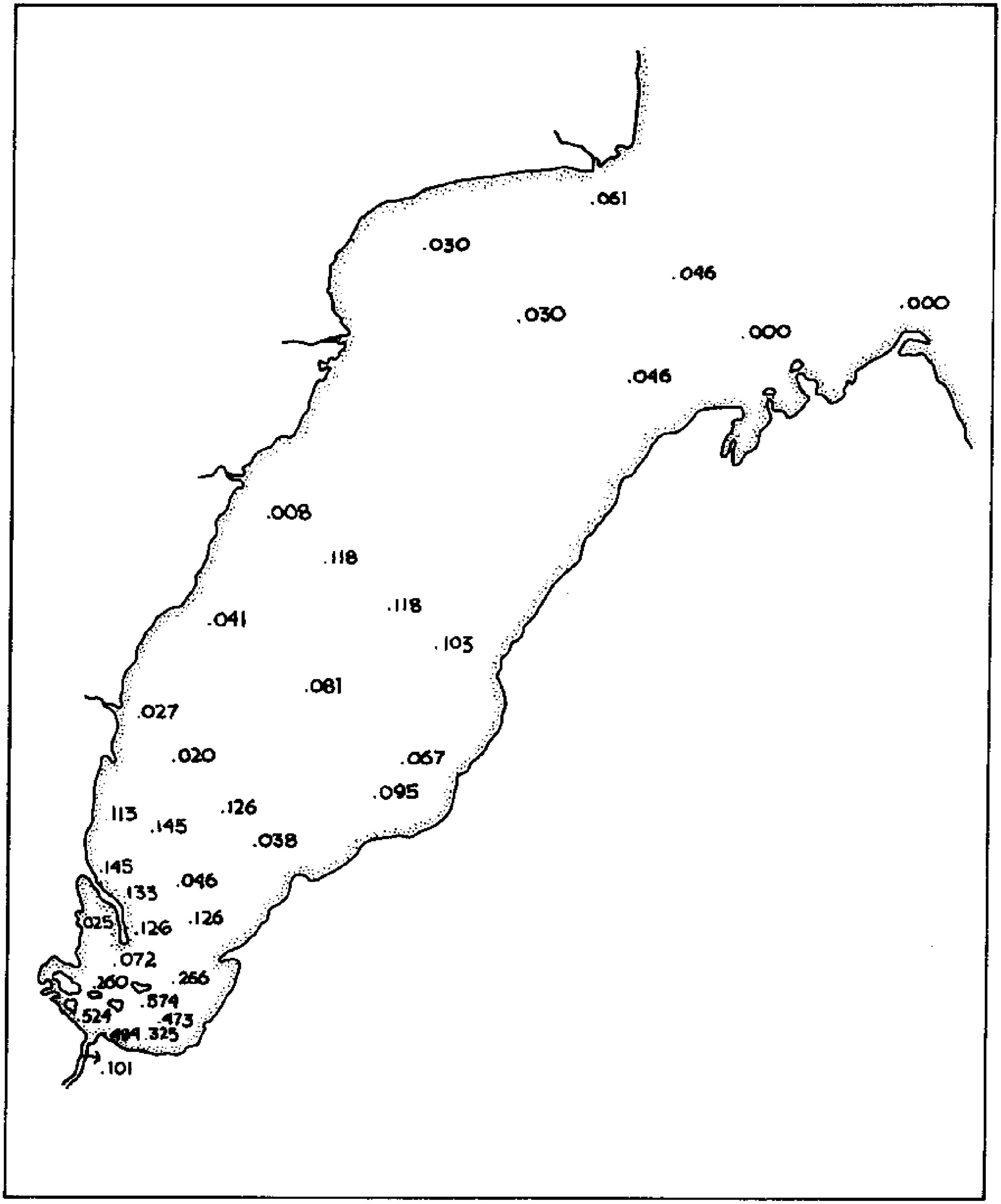


Figure 15. Ammonia Nitrogen (mg n/l). From Wisconsin Department of Natural Resources, September 1973.

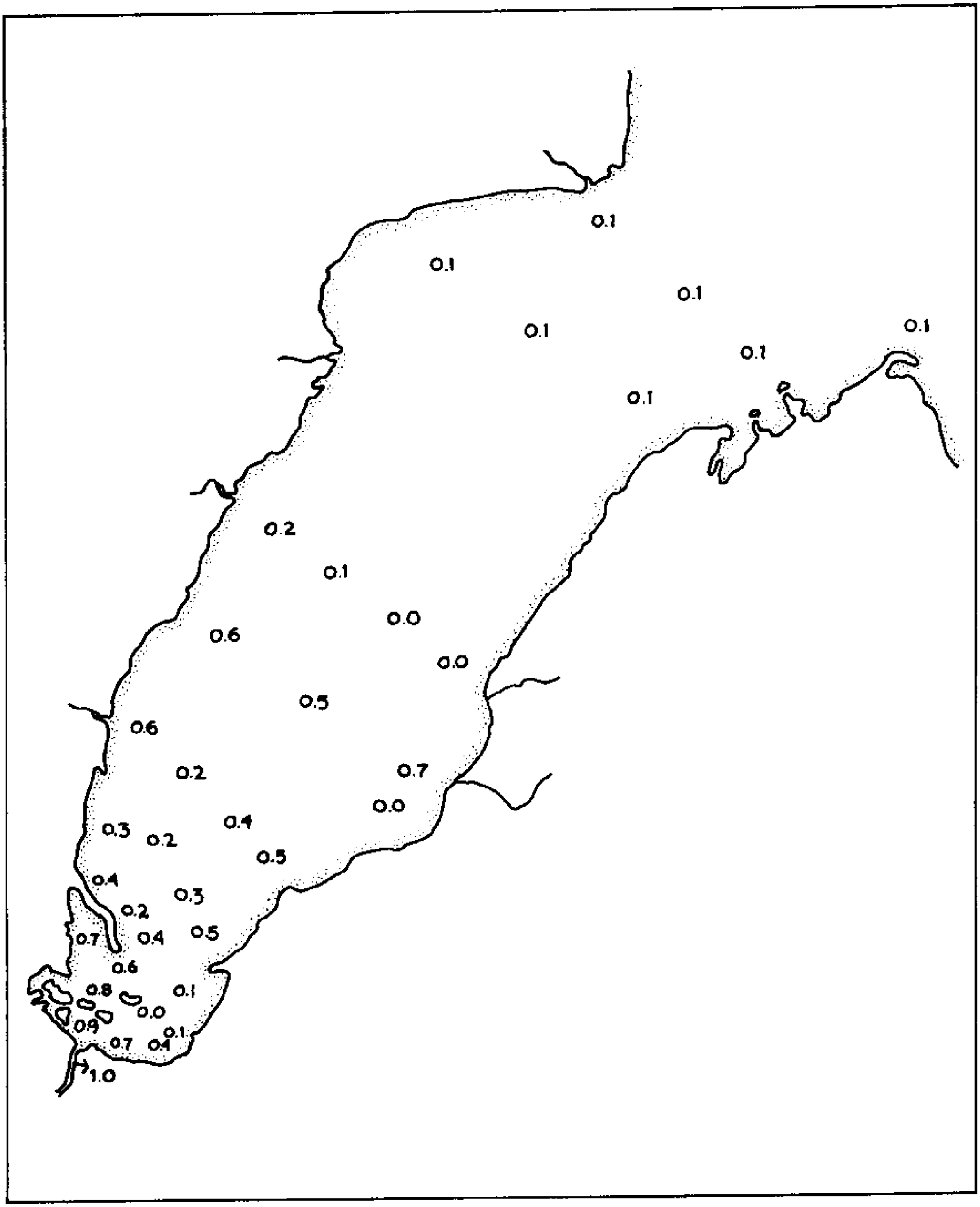


Figure 16. Organic Nitrogen (mg n/1). From Wisconsin Department of Natural Resources, September 1973.

higher levels of ammonia nitrogen and organic nitrogen in the lower bay (Figures 15 and 16).

As with phosphorus, non-point sources of nitrogen will continue to be a problem in Green Bay even if pollution abatement succeeds in reducing nitrogen loadings from industrial and municipal sources.

3. BIOLOGICAL CHARACTERISTICS OF GREEN BAY

3.1 BENTHOS

Because benthic (bottom dwelling) animals are recognized indicators of water quality, they are discussed here in detail and take chronological priority over later discussions of zooplanton and phytoplankton.

Benthic organisms are particularly good indicators of environmental conditions, because they live in direct contact with the sediment which is the ultimate recipient of most pollution. Many benthic organisms feed directly on the sediment, extracting organic materials from it. Because benthic organisms are essentially sedentary in nature, there is greater confidence in conclusions derived from benthic data than from data on more mobile kinds of organisms. The sedentary habit also means that direct comparisons can be made among benthic surveys in which different methods, materials and sampling stations were used.

The large number of species and individuals in the benthos means that a consequential shift in species composition with changing conditions is easily detectable. Even minor changes are discernible if there are sufficient baseline data. In lower Green Bay there is no need to search for subtle changes. The gross effects of the Fox River system on the bay are strongly reflected in the fauna.

Over the past 30 years, changes in the composition of the benthic fauna of southern Green Bay have been particularly well documented. The first quantitative survey of benthic organisms in lower Green Bay was made between November 1938 and February 1939, and samples were presumably taken through the ice (Wisconsin State Committee on Water Pollution, 1939). Eight of the nine stations sampled had 20 or fewer pollution tolerant worms (Tubificidae, Oligochaeta) per square foot. Levels of midge larvae (Chironomidae, Insecta) were similar. (Both the tubificid worms and midge larvae are recognized indicators of degraded conditions [Goodnight and Whitley, 1960; King and Ball, 1964].) In 1938-39, the only station with large numbers of tubificids was off the mouth of the Fox River, slightly to the east, in the direct path of the river plume.

Thirteen years later, during the spring, Surber and Cooley (1952) resurveyed nine of the stations sampled in 1938, plus 18 others (Tables 14 and 15a). There was a dramatic increase over the 13-year period in the numbers of both pollution tolerant worms and midge larvae. It is possible that seasonal depression in the numbers of individuals collected in the winter of 1938-39 may have accentuated the differences found in the two surveys. Seasonal differences in number could be very sharp in a shallow, polluted bay. Nevertheless, Surber and Cooley concluded that there was a significant increase in the bottom pollution in the intervening 13 years.

A third benthic survey was done in January 1955 (Balch et al., 1956). The study found very low numbers of individuals when compared to earlier studies at the same positions. The highest number of tubificids reported was 244 per square foot $2684/m^2$ inside Long Tail Point. The number of midge larvae (four species) varied by 0 to 16 per square foot (0 to $172/m^2$).

Table 14. Comparison of the Numbers per Square Foot of Tubificid Worms and Midge Larvae Between 1938 and 1952

1952 Station Number *	Comparable 1938-39 Station Number*	1952 Tubificidae	1938-39 Tubificidae	1952 Chironomidee	1938-39 Chironomidae
2	S-11	10,516	2,200	128	270
3	G-29	3,144	20	288	64
4	G-30	4,756	4	152	2
5	G-11	1,252	8	156	100
6	G-31	912	4	164	180
8	G-17	132	2	212	38
10	G-9	72	None	108	None
12	G-7	196	None	156	72
14	G-5	84	None	144	None

From Surber and Cooley (1952)
*See Appendix, Figure 80, for station locations.

Tubificid worms varied from 0 to 139 per square meter (0 to 2,627/m^2). Fourteen of the 93 winter samples from the Bay had no living animals. The diversity, the number of species present, and the distribution of individuals among species increased with distance from the mouth of the Fox.

Balch et al., (1956) concluded that there had been a reduction of pollution in the bay and dismissed the seasonal variation as a cause for the low numbers of individuals. Regarding this latter possibility, Howmiller and Beeton (1971) state:

> It is not clear why the possibility of a winter minimum of population density was treated so lightly. Great reduction in numbers of oligochaetes may occur during winter months.

Such a winter reduction in numbers was demonstrated for oligochaetes by Howmiller and Beeton (1970) and is likely true for other invertebrate groups as well.

The 1962-63 U.S. Federal Water Pollution Control Administration's (FWPCA) benthic survey (USDI, 1966) is of limited use. While different benthic surveys can be compared, as noted above, the difficulties of comparison due to different sample locations, sampling gear, and seasons should not be underestimated. Apparently, they were in this case. The sampling stations differed from those of earlier surveys, the sampling times were not given and the generalized identification of the faunal components allow only qualitative rather than quantitative comparison. In the FWPCA survey, the total number of organisms in the Fox River area ranged from 455 to 1,364 per square foot (5,000 to 15,000/m^2). Near the river mouth, there were fewer oligochaetes and midge larvae than in earlier surveys. But at a distance of 3 to 4 miles (5 to 15 km) up the bay, there were more tubificides and midge larvae than in previous surveys (Figure 17).

As in the earlier studies, total numbers generally decreased with distance from the mouth of the Fox River. This was due to a decline in the abundance of pollution tolerant fauna and a gradation into a more typically oligotrophic, less abundant, pollution intolerant fauna. There were 500 organisms per square meter 10 miles (16 km) from the river mouth.

The mouth of the Oconto River was sampled in some detail by the FWPCA team and a total of 182 to 455 per square foot (2,000 to 5,000/m^2) were found there (Figure 17). The mouth of the Peshtigo had 73 per square foot (800/m^2) and the Menominee had 227 per square foot (2,500 organisms/m^2). The Oconto and Peshtigo had a rapid decrease of pollution tolerant species with distance from the mouth (Figure 18).

The FWPCA survey found nymphs of the pollution-sensitive burrowing mayfly Hexagenia only in one aera. In the earlier 1938-39 study, they were present in two of the nine stations sampled. Schraufnagel et al., (1968) ascribed this decline to the low oxygen levels during winter months.

Schraufnagel et al., (1968) resurveyed the benthos in 1966-67 as part of a pollution investigation of the Fox River and the bay proper. The investigation defined the bay into three sections:

Lower Green Bay—the southern 10 miles of the bay from the entrance light to the mouth of the Fox River.

Middle Green Bay—from the entrance light to Sturgeon Bay approximately 35 miles from the mouth of the Fox River.

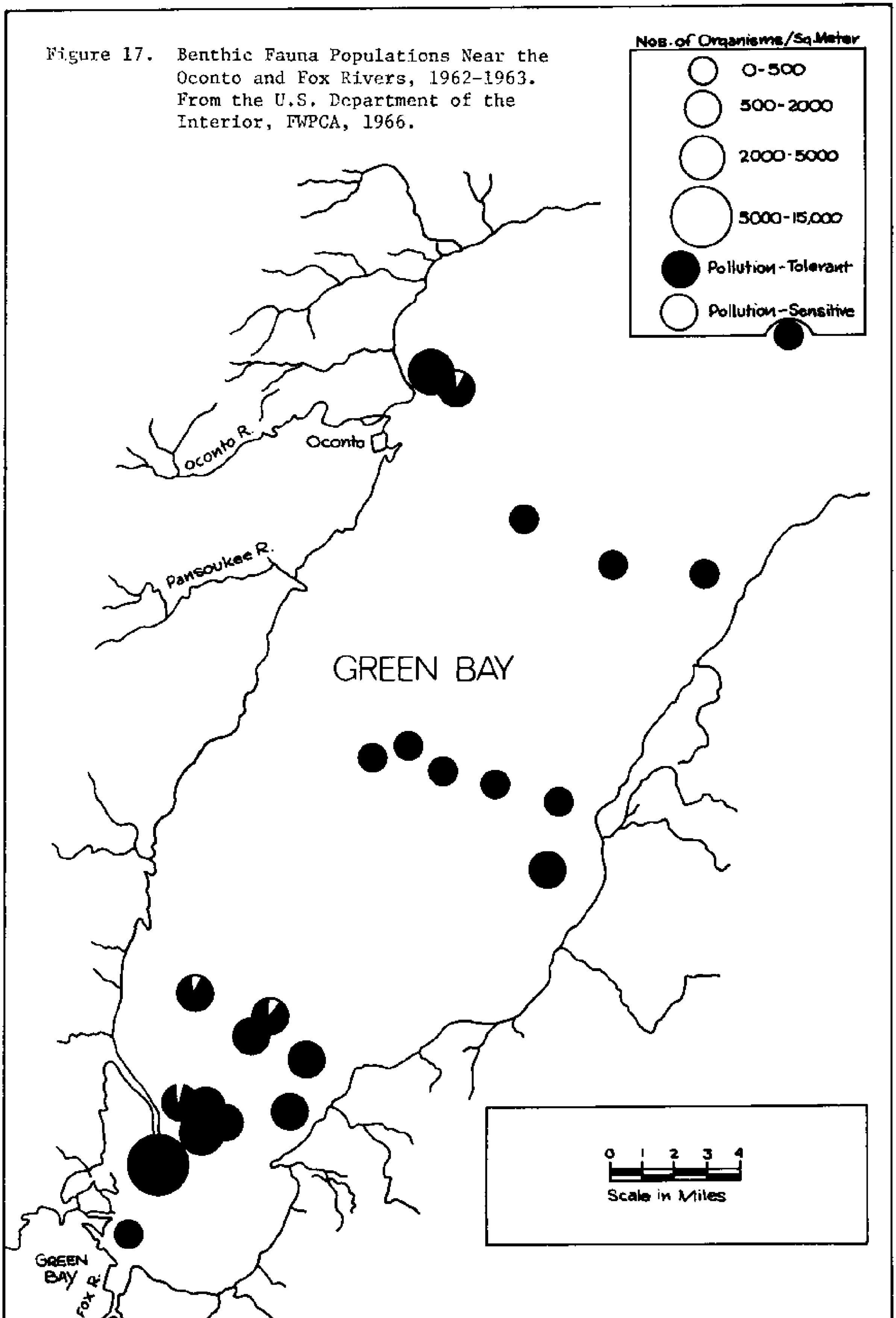
Outer Green Bay—from Sturgeon Bay to Washington Island approximately 70 miles from the mouth of the Fox River.

The large region north of Washington Island lying in Michigan was not sampled in the survey.

In the lower bay, the macrofauna was dominated by tubificid worms and midge larvae. The inner 1.5 miles (2.4 km) of the channel was devoid of benthic invertebrates. This was ascribed to the hard clay bottom and scour activity of vessel traffic. The very low dissolved oxygen levels are probably also a major cause for the absence of organisms. But the effects of oxygen levels and bottom scour from vessel traffic were not differentiated. While there were no living bottom invertebrates within 1-1/2 miles (2.2 km) of the channel, there were 1 to 25 benthic animals per square foot (10 to 275 /m^2) at a distance of 1-1/2 to 2 miles (2.2-3.4 km) west of the channel. Three miles (5 km) east of the channel, 20 to 25 organisms per square foot (220 to 275/m^2) were found. The number of individuals in the channel sediments increased with increasing distance from the mouth of the Fox.

Between Long Tail Point and the entrance light, two samples had 136 and 292 tubificids per square foot (1500 and 3200/m^2). The total number of organisms generally was under 109 per square foot (1,200/m^2). Midge larvae comprised less than 30 percent of the total, which was dominated by tubificid worms.

Figure 17. Benthic Fauna Populations Near the Oconto and Fox Rivers, 1962-1963. From the U.S. Department of the Interior, FWPCA, 1966.



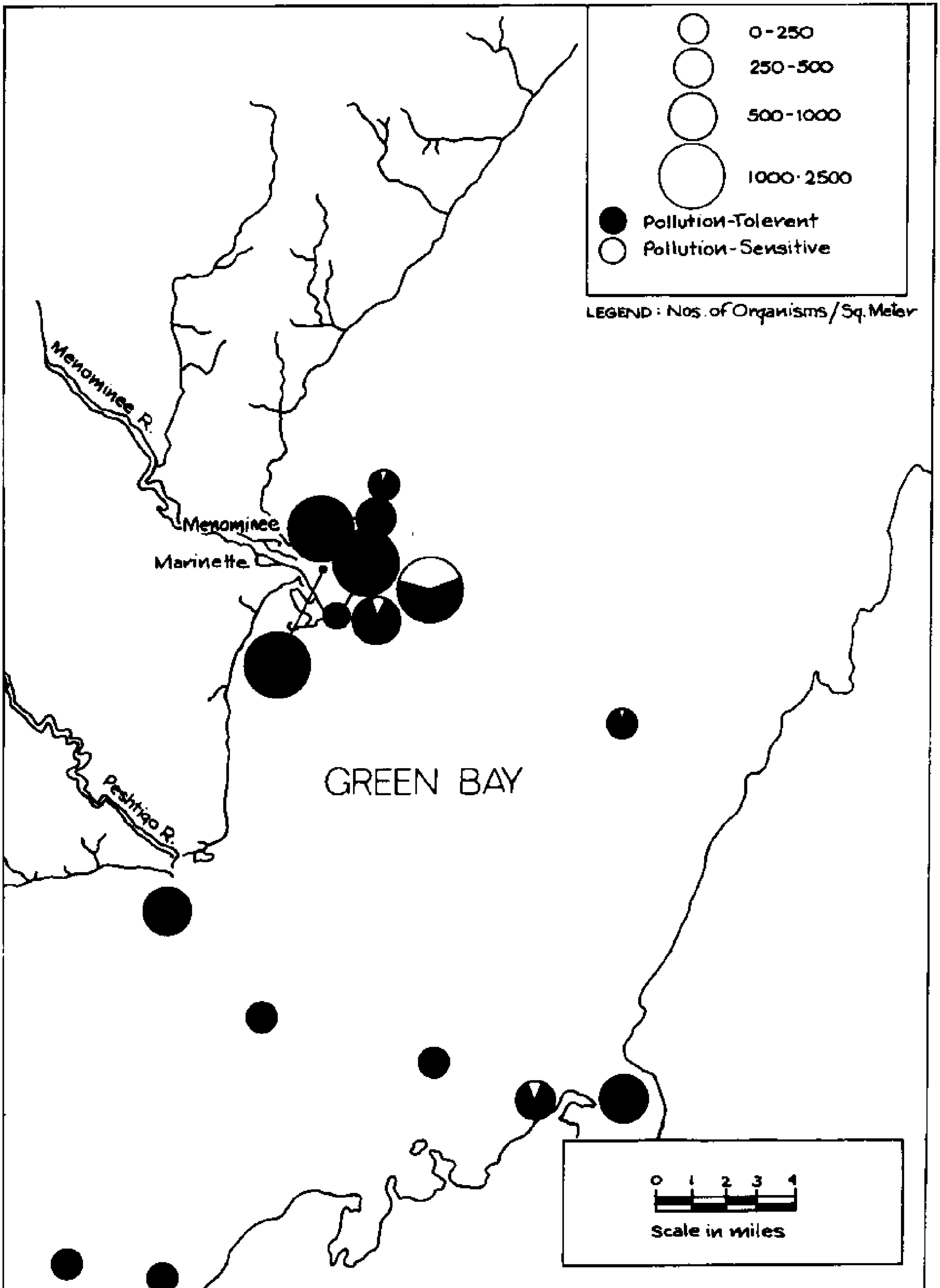


Figure 18. Benthic Fauna Populations Near the Menominee and Peshtigo Rivers, 1962-1963. From the U.S. Department of Interior, FWPCA, 1966.

In the middle bay the benthic fauna was again dominated by tubificids, with a population generally less than 150 organisms per square foot (1,600/m^2). Midge larvae (Chironomus) were common, with densities of 20 per square foot (220/m^2). The pollution intollerant mayfly, Hexagenia, was not observed.

Outer Green Bay was dominated by pollution intolerant species. At 40 miles (64.5 km), significant numbers of the shrimp Pontoporeia affinis appeared. This species is typical of the well-aerated water of Lake Michigan.

The work of Howmiller and Beeton (1970, 1971) provides the best quantitative data on the Green Bay benthos. The samples were taken in the same manner and locations as those used by Surber and Cooley in 1952. This allowed direct comparison with the earlier quantitative survey. One hundred and three stations from the mouth of the Fox to Washington Island were sampled in 1966, 1967 and 1969. A 23-cm Ekman grab and a U.S. Standard No. 30 sieve were used. Because the earlier survey of Surber and Cooley had used a 15 cm. grab, there was some difference in depth of penetration and area surveyed. In neither survey were replicate samples taken to determine variability within a station between samples. The magnitude of this error was weighed and dismissed by Surber and Cooley as smaller than the effort needed to correct it.

The organisms collected by Howmiller and Beeton were specifically identified, and many of the results found by Howmiller and Beeton (1970) are based on the exacting identification of Oligochaeta. For many years this major taxonomic group was neglected, and as late as 1966 (Henson, 1966) it was estimated that only 10 species occurred in the Great Lakes. In the past few years, at least 51 species have been identified from the Great Lakes (30 from Green Bay), and more can be expected.

In 1966 and 1967 Oligochaetes were found to comprise 60 percent of the invertebrates in the samples from the lower 10 miles of the bay inside the entrance light, and 50 percent of the samples from the northern portion of the bay. Other invertebrate groups in order of abundance were: midge larvae, amphipods, isopods, leeches, mollusks, and mayfly nymphs of the genus Caenis. The "Green Bay fly" (Hexagenia), so common in 1938-39, was not found, and this highly pollution intolerant species appears to have disappeared from the bay just as it did from western Lake Erie (Carr and Hiltunen, 1965).

Dramatic seasonal effects were noted in the bottom fauna. Oligochaete densities on the lower bay decreased from an average of 307 to 124 per square meter (3,381 to 1,366/m^2) from October to May. At some stations, the levels in May were only 3 to 4 percent of the October levels. Howmiller and Beeton (1970) ascribed this, as did Schraufnagel (1966), to anoxic water conditions under the winter ice.

Based on the data from their follow-up survey in 1969, Howmiller and Beeton (1971) concluded that polluted conditions were steadily moving up the Bay and along the eastern shore. In comparing their 1969 findings with those of Surber and Cooley (1952), Beeton and Howmiller showed that over the 17-year period, pollution intolerant species had decreased uniformly. Leeches, snails, fingernail clams and amphipods had declined markedly (Figures 19, 20, 21, and 22). Simultaneously, both oligochaetes and chironomid larvae had increased in abundance (Figures 23 and 24). In 1952, oligochaetes comprised 66 percent of the total organisms. This number increased to 85 percent in 1969 (Figure 28). Tables 15a and b compare the results of the 1952 and 1969 studies.

TABLE 15a

Abundance of Benthic Invertebrates on 26 and 27 May 1952*
(See Appendix, Figure 80, for station locations)

Station	Nematodes	Oligochaetes	Leeches	Snails	Clams	Amphipods	Isopods	Midges	Other
	Abundance of Given Invertebrate (no./sq m)								
1	0	43	0	0	0	0	0	129	43 Eristalis
2	0	113,152	86	0	258	0	0	1,377	
3	0	33,829	0	0	0	0	0	3,099	
4	0	51,175	43	0	0	0	0	1,636	
5	0	13,472	43	0	0	0	43	1,679	
6	0	9,813	86	172	344	0	0	1,765	
7	0	2,109	215	258	732	0	0	1,679	
8	0	1,420	86	129	732	0	0	2,281	
9	0	2,324	86	301	2,668	0	0	947	
10	0	775	258	43	516	0	0	1,162	
11	0	897	0	258	75	710	11	86	11 Caddis, Molanna
12	0	430	43	86	516	0	0	344	
13	0	258	43	43	1,592	0	0	258	
14	0	904	0	43	603	0	0	1,549	
15	0	603	0	0	732	560	301	990	
16	43	1,033	129	0	1,420	0	0	1,334	
17	0	86	0	0	0	0	0	301	
18	0	387	43	0	301	0	0	646	
19	0	43	344	0	43	0	0	86	
20	0	581	0	0	129	0	0	2,539	
21	0	861	258	43	603	0	0	646	
22	0	818	43	0	473	0	0	775	
23	0	0	129	0	301	0	0	646	
24	0	0	129	0	0	0	0	818	
25	0	301	43	0	387	0	0	560	
26	0	387	0	0	301	0	0	1,291	
27	0	516	0	0	258	43	0	2,410	

*from Surber and Cooley (1952)

TABLE 15b

Abundance of Benthic Invertebrates on 26 May 1969***
(See Appendix, Figure 80 , for station locations)

Station	Nematodes	Oligochaetes	Leeches	Snails	Clams	Amphipods	Isopods	Midges	Other
	Abundance of Given Invertebrate (no.sq m)								
1	0	0	0	0	0	0	0	0	96 Psychoda
2	+	22,657	0	0	0	0	0	38	
3	0	8,604	0(114)**	0	0	0	0	688	
4	+	7,227	0	0	0	0	0	440	
5	+	29,292	0	0	0	0	0	2,237	
6	+	16,921	0	0	0	0	0	3,155	
7	+	11,854	76	0	38	0(19)**	0	1,778	
8	+	4,264	0(113)**	0	57	0	0	860	
9	+	2,008	19	0	631	0	0	1,759	
10	+	1,032	19	0	19	0	0	76	
11	+	1,663	0	0(38)**	172	0(38)**	0(19)**	402	
12	+	822	0	0	994	0	0	1,836	
13	+	688	0	19	268	0	0	1,644	
14	+	918	0	0	19	0	0	3,097	19 Lampsilis
15	+	2,792	0	19	1,166	19	0	554	
16	+	1,281	0	0	0	0	0	1,128	
17	+	1,109	0(38)**	0	0(19)**	0	0	918	
18	+	229	0	0	0	0	0	707	
19	+	4,531	0	0	57	0	0	2,314	
20	+	2,658	0	0	0	0	0	2,065	
21	+	5,354	0	0	0	0	0	803	
22	+	1,740	0	0	0	0	0	1,530	
23	+	899	0	0	0	0	0	344	
24	+	9,770	19	0	0	57	76	1,300	
25	+	10,325	0	0	10	38	38	631	
26	+	23,441	0	0	0	0	0	1,166	
27	+	10,095	0	0	0	19	0	2,275	

*Nematoda were very numerous in many samples but certainly not sampled quantitatively, hence not counted.
**Not taken in Ekman grab sample but numbers of animals in paranthesis were recorded from Ponar grab sample taken at the same time.
***From Howmiller and Beeton, 1971.

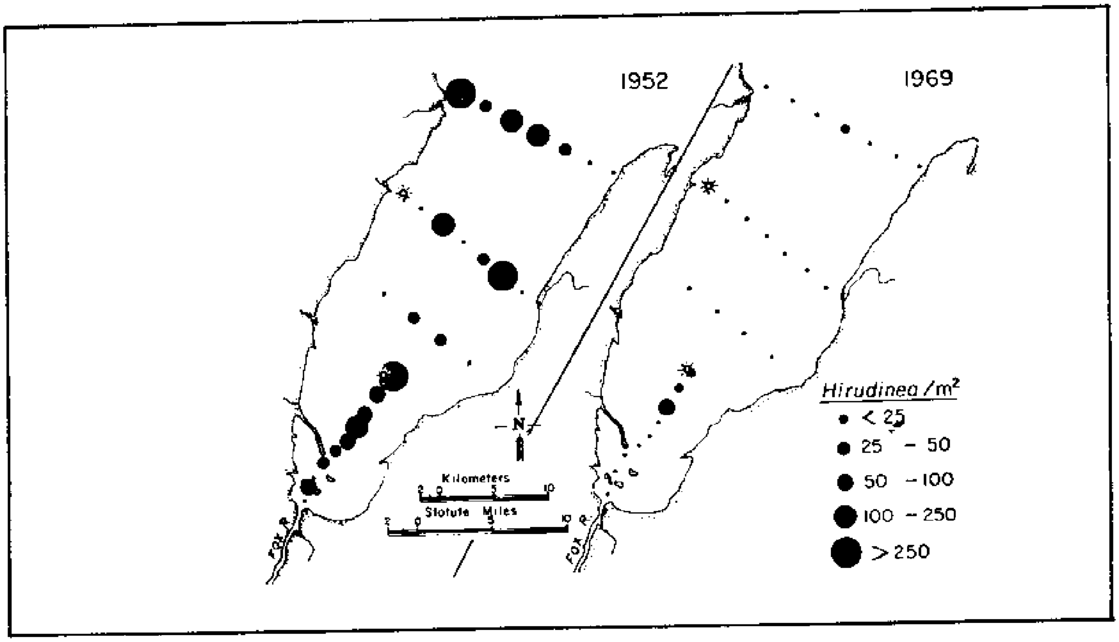


Figure 19. Distribution and abundance of leeches in May 1952 and 1969. From Howmiller and Beeton 1971.

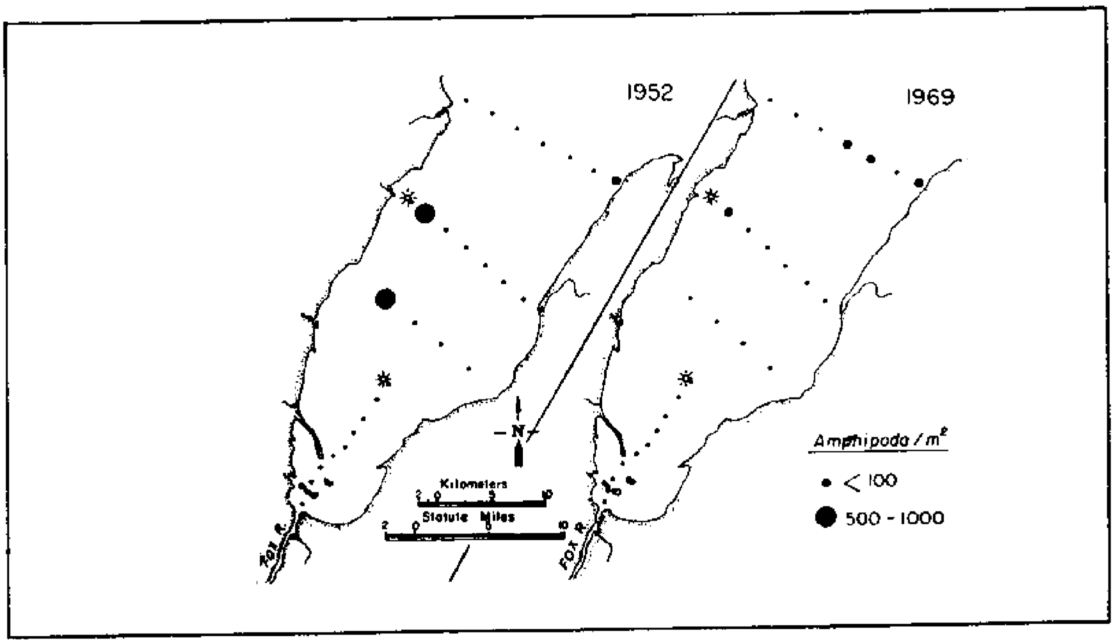


Figure 20. Distribution and abundance of amphipods in May 1952 and 1969. From Howmiller and Beéton 1971.

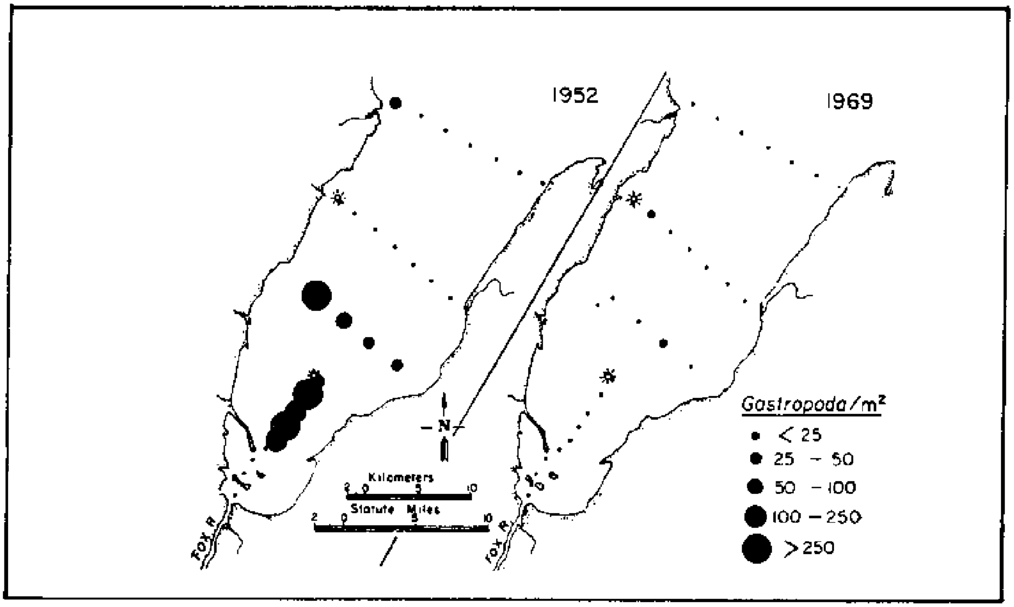


Figure 21. Distribution and abundance of snails in May 1952 and 1969. From Howmiller and Beeton, 1971.

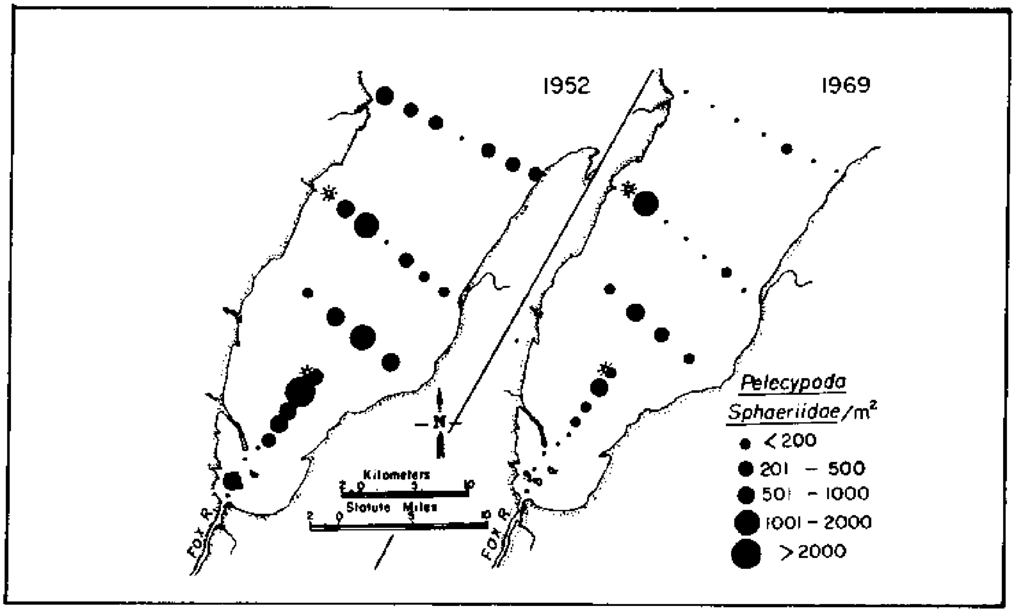


Figure 22. Distribution and abundance of fingernail clams in May 1952 and 1969. From Howmiller and Beeton, 1971.

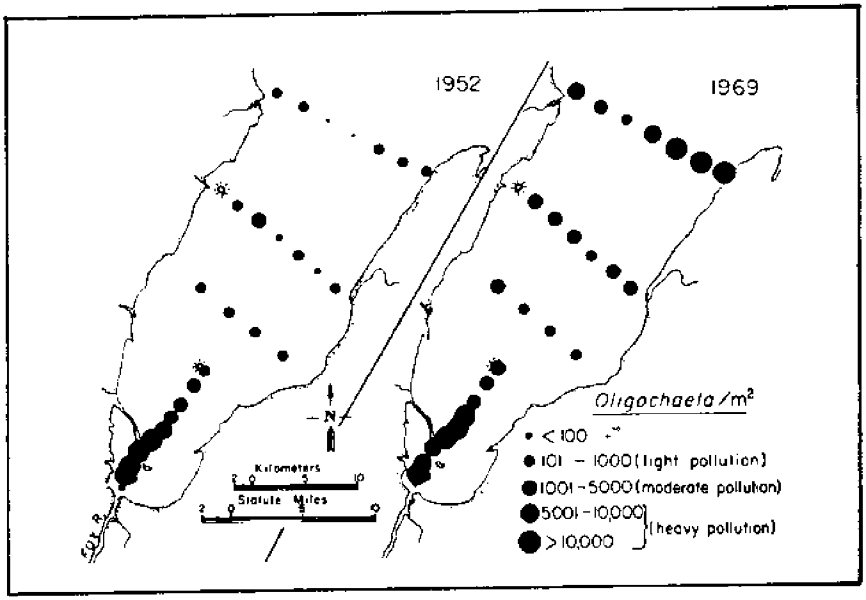


Figure 23. Distribution and abundance of Oligochaeta in May 1952 and 1969. From Howmiller and Beeton, 1971.

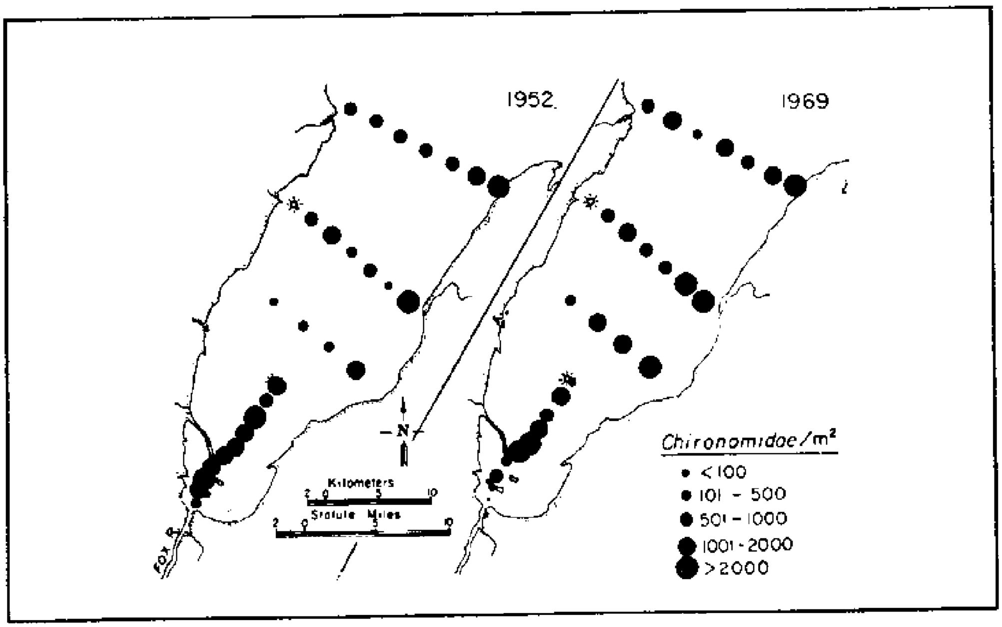


Figure 24. Distribution and abundance of Chironomidae in May 1952 and 1969. From Howmiller and Beeton, 1971.

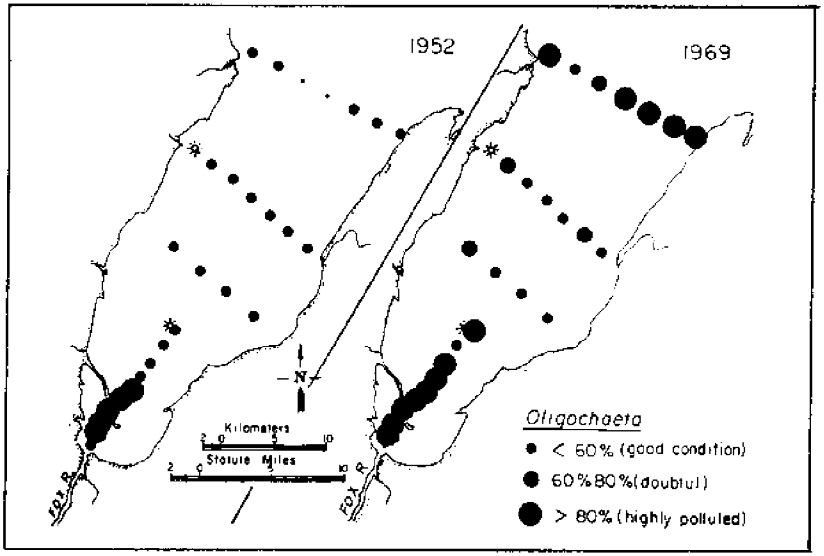


Figure 25. Relative Abundance of Oligochaeta, as Percentage of Total Bottom Fauna in May 1952 and 1969. From Howmiller and Beeton, 1971.

Midges decreased south of Long Tail Point but increased at all stations to the north. The anoxic conditions around the Fox River mouth during the summer months are apparently more than even these tolerant organisms can stand. The total number of midges in the samples increased over the 17 years. Nevertheless, the great increase in olgiochaete abundance caused the relative importance of the midges to fall from 48 percent to 37 percent of the total number of organisms sampled in the middle bay and from 37 percent to 26 percent of those sampled for the bay as a whole.

There are some anomalies between the two studies (See Tables 14 and 15). For example, at two stations inside Longtail Point the 1952 survey found 10,287 and 4,652 oligochaetes per square foot (113,152 and 51,175/m^2). These same stations in 1969 had 2,151 and 657 oligochaetes per square foot (23,657 and 7,227/m^2) respectively. The highest density found in the 1969 survey was 2,663 oligochaetes per square foot (29,292/m^2) just off Longtail Point. In addition, the 1969 survey has numerous uncounted nematodes, where in 1952 only 43 nematodes were found and these were all at one station.

As part of the Pulliam Power Plant study of 1973 (Wisconsin Public Service Corporation, 1974), benthic samples were taken at 27 stations in the lower bay inside Long Tail Point, using a 23-cm. Ponar grab. After processing a small portion sample, the numbers were projected to a square meter. Only gross identification to major taxas was made. Oligochaetes were found to be 58 percent of the organisms collected within the inner bay, as compared to 85 percent of the organisms collected within the inner bay found by Howmiller and Beeton (1971). The power plant study compared their 58 percent figure to the 60 percent oligochaete abundance figure reported by Howmiller and Beeton (1970) for the inner 10 miles (16 km) of the bay. However, this was an error, since the power plant survey had the majority of its sampling stations outside Long Tail Point where oligochaete densities are lower. Nevertheless, the decrease in oligochaete densities reported in the Pulliam study may be due to diluting effect of the very high water levels of 1973 or it may be a result of sample treatment.

The 1973 Pulliam data show both the characteristic zone of minimal life at the river mouth—apparently resulting from anerobic conditions—and the zone in the lower bay typically dominated by oligochaetes and midge larvae. The seasonal variation in oligochaete and chironomid numbers observed by Howmiller and Beeton in 1970 was also seen in this study. Relatively small numbers of these organisms were taken between the months of April and August.

It was also noted in the Pulliam study that benthic copepods and cladocera show a reverse cycle of abundance from that of the dominant oligochaetes and midges. Copepod populations peak in abundance during the summer months (May to September), while cladocerans peak between April and June. The authors speculate that the disparity of population peaks may indicate that the seasonal variation of benthos numbers may be more a function of life cycles than of reduced oxygen concentrations. Considerable work still needs to be done on the seasonal dynamics of the benthos in Green Bay before the observed patterns are understood.

Two measures of pollution based on the benthic fauna are applicable to Green Bay. Wright (1955) used a standard based on oligochaetes per square meter in Lake Erie: Light pollution 100 to 999, moderate, 1,000 to 5,000, and heavy, greater than 5,000. By this standard, the inner bay is heavily polluted and the middle bay has gone from lightly to polluted in 1952 to moderately polluted in 1969. Goodnight and Whitley (1961) suggested a standard based on oligochaetes as a percent of the fauna: good condition, less than 60 percent oligochaetes; doubtful condition, 60 to 80 percent; and highly polluted, more than 80 percent oligochaetes. By these standards, the lower bay has gone from doubtful to highly polluted and the middle bay from good condition to doubtful condition since 1952.

Aquatic mites may be another indicator group. Modlin and Gannon (1972) reported the presence of aquatic mites in the benthos, neuston, and plankton of Green Bay. Although mites were particularly abundant in the shallow inshore areas, they are generally relatively scarce (both in biomass and numbers) in the Great Lakes. The investigators postulated that the scarcity results from the absence of aquatic macrophytes and attached algae which are preferred habitat of mites. Mites are expected to increase in the bay with increasing eutrophication and the spread of aquatic plants such as Cladophora glomerata.

Benthic species distribution in the bay seems to be directly related to water quality, although sediment distribution may also play a part. Pollution tolerant species occur in greatest abundance in the lower bay and along the east side of the bay northward (Figures 17 and 18). Pollution intolerant species occur in the northern and western portions of the bay. Polluted areas are dominated by the tubificid Limnodrilus hoffmeisteri and the naidid Dero digitata; in clean waters the lumbriculid, Stylodrilus heringianus and turbificid, Tubifex kessleri are found, as well as an increasing proportion of other faunal groups.

Howmiller and Beeton (1971) pointed out that Green Bay is following the path of Lake Erie and that many of the changes documented there are occurring in Green Bay: the increase in oligochaetes and midges; the disappearance of Hexagenia; the decline of intolerant groups such as leeches, snails, and clams; and the increase of the abiotic zone. The authors concluded that benthic fauna can continue to serve as a major indicator of the progress or regression of polluted conditions in the bay.

3.2 ZOOPLANKTON

Zooplankton are the small invertebrate animals that float or swim in the water column. Their community is generally dominated by small crustaceans of various kinds although aquatic insect larvae are periodically important. Zooplankton graze on algae and organic debris and some feed on other small aquatic animals. In turn, zooplankton are preyed upon by young fish as well as some adult fish.

Though not as reliable as benthic organisms, zooplankton also serve as indicators of water quality.

Knowledge of the zooplankton of Green Bay is based primarily on the work of Balch et al., (1956); Torke, in Howmiller and Beeton, eds. (1973); Gannon (1972a and 1972b); and Wisconsin Public Service Corporation (1974).

The 1955 surveys by Balch et al. (1956) concentrated on the Fox River, although some zooplankton samples were taken in the bay. Organisms were identified only as copepods or cladocerans. Torke (1973), however, sampled seven stations in southern Green Bay and identified 17 species of crustaceans: nine cladocerans and eight copepods; and one rotifer.

Torke found that the most common species were the herbivores Daphnia retrocurva and Eubosmina coregoni. The copepod Diaptomus ashlandi was found only at the northern bay stations. D. retrocurva, E. coregoni and the predators Leptodora kindtii and Asplanchna sp. were several times more abundant in the eastern and southern stations than in other areas sampled. However, this distribution may not be a function of trophic conditions.

Torke also compared Green Bay zooplankton species with those of Lakes Erie and Michigan (Table 16). Torke found that Cylops vernalis, which was confined to southern Bay stations, and Diaptomus siciloides are both common in the eutrophic western basin of Lake Erie. These species are uncommon or absent in the cleaner waters of eastern Lake Erie or Lake Michigan. Gannon (1972a) suggests that Diaptomus siciloides may be a useful early indicator of advancing eutrophication because it apparently is not subject to size-selective fish predation, thus eliminating one major variable of distribution.

Only one of Torke's Green Bay sampling stations was thermally stratified. This station was the only one in which many of the cold-water zooplankton forms common in Lake Michigan were found. The station was also distinctive in having twice the plankton biomass of any other sampling point.

Gannon (1972a and 1972b) looked at the effects of eutrophication and fish predation on the distribution of zooplankton crustaceans in Lake Michigan and Green Bay. Major differences in species composition exist between the bay and Lake Michigan. Daphnia pulex, Diaptomus siciloides, and Moina micura occur only in Green Bay. Large species, reduced in numbers in Lake Michigan by the selective predation of alewives, are still abundant in Green Bay According to Gannon, the greater turnover rates in the bay allow the abundant larger species to withstand the predation pressure. The abundance of small species such as Ceriodaphnia and Eubosmina is ascribed to the zooplanktons' feeding adaptations to eutrophic conditions rather than to the selective predation of larger zooplankton forms by fish. In general, alewives appear to have a greater impact on zooplankton in oligotrophic waters than in the eutrophic waters of Green Bay.

Table 16. Crustacean species collected in Green Bay on 12 July 1971, compared with July collections from Lakes Michigan and Erie (Lake Michigan data from Wells 1970; Lake Erie data from Davis 1968).

- = Virtually absent or absent
X = Presence in small numbers
C = Common (present in numbers often exceeding $100/m^3$)
A = Abundant (present in numbers often exceeding $1000/m^3$)

CLADOCERA	Green Bay	Lake Michigan	W. Lake Erie	Central & E. Lake Erie
Ceriodaphnia lacustris Birge	C	X	-	-
Daphnia retrocurva Forbes	A	A	A	C
D. galeata mendotae Birge	C	C	A	A
D. longiremis Sars	X	X	-	-
D. parvula Fordyce	X	-	-	-
D. pulex leydig Fischer	-	-	X	-
Diaphanosoma leuchtenbergiana Fischer	-	X	X	-
Holopedium gibberum Zaddach	-	C	-	X
Bosmina longirostris (O. F. Muller)	C	C	-	-
Eubosmina coregoni (Baird)	A	C	A	C
Chydorus sphaericus (O. F. Muller)	X	X	X	X
Polyphemus pediculus (L.)	-	X	-	-
Leptodora kindtii (Focke)	C	C	C	C
COPEPODA				
Limnocalanus macrurus Sars	-	C	-	-
Senecella calanoides Juday	-	X	-	-
Epischura lacustris Forbes	-	C	-	-
Eurytemora affinis (Poppe)	X	X	X	-
Diaptomus minutus Lilljeborg	-	C	X	X
D. ashlandi Marsh	X	C	X	X
D. oregonensis Lilljeborg	X	C	X	C
D. sicilis Forbes	-	X	-	-
D. siciloides Lilljeborg	C	-	C	X
Cyclops bicuspidatus thomasi Forbes	C	A	A	A
C. vernalis Fischer	C	-	C	-
Tropocyclops prasinus mexicanus Kiefer	X	X	-	-
Mesocyclops edax (S. A. Forbes)	X	X	X	C

from Torke, in Howmiller and Beeton, eds., 1973.

Gannon proposed that selective feeding by fish modifies the utility of zooplankton indicator species and suggested that the relative rotifer and cladoceran/copepod ratios may be a better indication of conditions. For example, in Green Bay and western Lake Erie, rotifers and cladocerans are relatively more abundant during summer months than copepods, where the opposite is true in Lake Michigan and eastern Lake Erie (Davis, 1968).

Gannon also studied zooplankton productivity rates in Green Bay. He found that summer primary production rates in Green Bay were approximately ten times that of Lake Michigan (Schelske and Callender, 1970) and that the standing crop of zooplankton in southern Green Bay was substantially higher than in Lake Michigan.

In the Pulliam thermal plume study (Wisconsin Public Service Corporation, 1974), 30 species of zooplankton were collected in the Fox River mouth and lower bay from January to November 1973 (Table 17). As found in Gannon's work, rotifers were the dominant group, with cladocerans second. The five most common species were the rotifers Keratella cochlearis, Filina longiseta, Brachionus sp., Polyarthra sp., and the cladoceran Bosmina longirostris. All of these species are small and all herbivorous. This dominance of small forms is ascribed specifically to differential feeding by alewives. It is disappointing that the authors of the thermal study did not cite or discuss Gannon's work (1972a and 1972b) which rejected this hypothesis. The Pulliam study relied instead on earlier work of Brooks (1969) and Wells (1970).

A comparison of the power plant survey with Well's (1970) survey of Lake Michigan zooplankton revealed that less than half of the copepod and cladoceran species found in Green Bay also occurred in Lake Michigan. In general, the species held in common by both areas were small in size, such as Cyclops and Daphnia. The six species which occurred in both the Bay and lake were from 1.5 to 300 times more abundant in Green Bay.

The Pulliam power plant study included an analysis of seasonal variation in zooplankton communities over 1973 (Figure 26). The populations built to summer peaks of 1.4 million individuals per cubic meter in July and dropped to 14,000 per cubic meter in February. Zooplankton populations increased with food availability and seemed to decline for the same reason. (In the fall, although much plant food is available, it has changed from smaller single-celled species to larger and colonial forms which cannot be effectively utilized by the zooplankton.) Seasonal changes in zooplankton were delineated with winter and spring populations dominated by the copepods Cyclops biscuspidatus thomasii, Diaptomus oregonensis and Nauplii. Rotifers begin to increase in March with Bracheonus sp. and Keratella cochlearis and K. quadrata as dominants. These are replaced in summer by Asplanchna sp., Polyarthra sp., and Filinia longiseta. Greatest abundance of zooplankton within the bay is on the west shore, where the highest phytoplankton and chlorophyll a values occur. The warmer areas associated with the power plant plume have higher year-round population peaks earlier and hold them longer.

Table 17. Zooplankton Species collected in Lower Green Bay and at the Mouth of the Fox River (January 1973 to November 1973)

COPEPODA

Cyclops bicuspidatus thomasii S. A. Forbes
Cyclops varicans rubellus Lilljeborg
Cyclops vernalis Fischer
Diaptomus oregonensis Lilljeborg
Eucyclops speratus Lilljeborg
Harpacticoid sp.
Macrocyclops albidus Jurine
Nauplii

CLADOCERA

Alona affinis Leydig
Bosmina coregoni Baird
Bosmina longirostris O. F. Muller
Chydorus spaericus O. F. Muller
Daphnia dubia Herrick
Daphnia galeata mendotae Sars Birge
Daphnia longiremis Sars
Daphnia pulex Leydig, Richard
Daphnia retrocurva Forbes
Daphnia schodleri Sars
Leptodora kindtii Focke

ROTIFERA

Asplanchna sp.
Brachionus sp.
Filinia longiseta Ehrenberg
Kellicottia longispina Ahlstrom
Keratella cochlearis Bory de St. Vincent
Keratella quadrata Bory de St. Vincent
Lecane depressa Harring and Myers
Notholca sp.
Polyarthra sp.
Rotaria sp.
Trichocerca sp.

from Wisconsin Public Service Corporation, 1974.

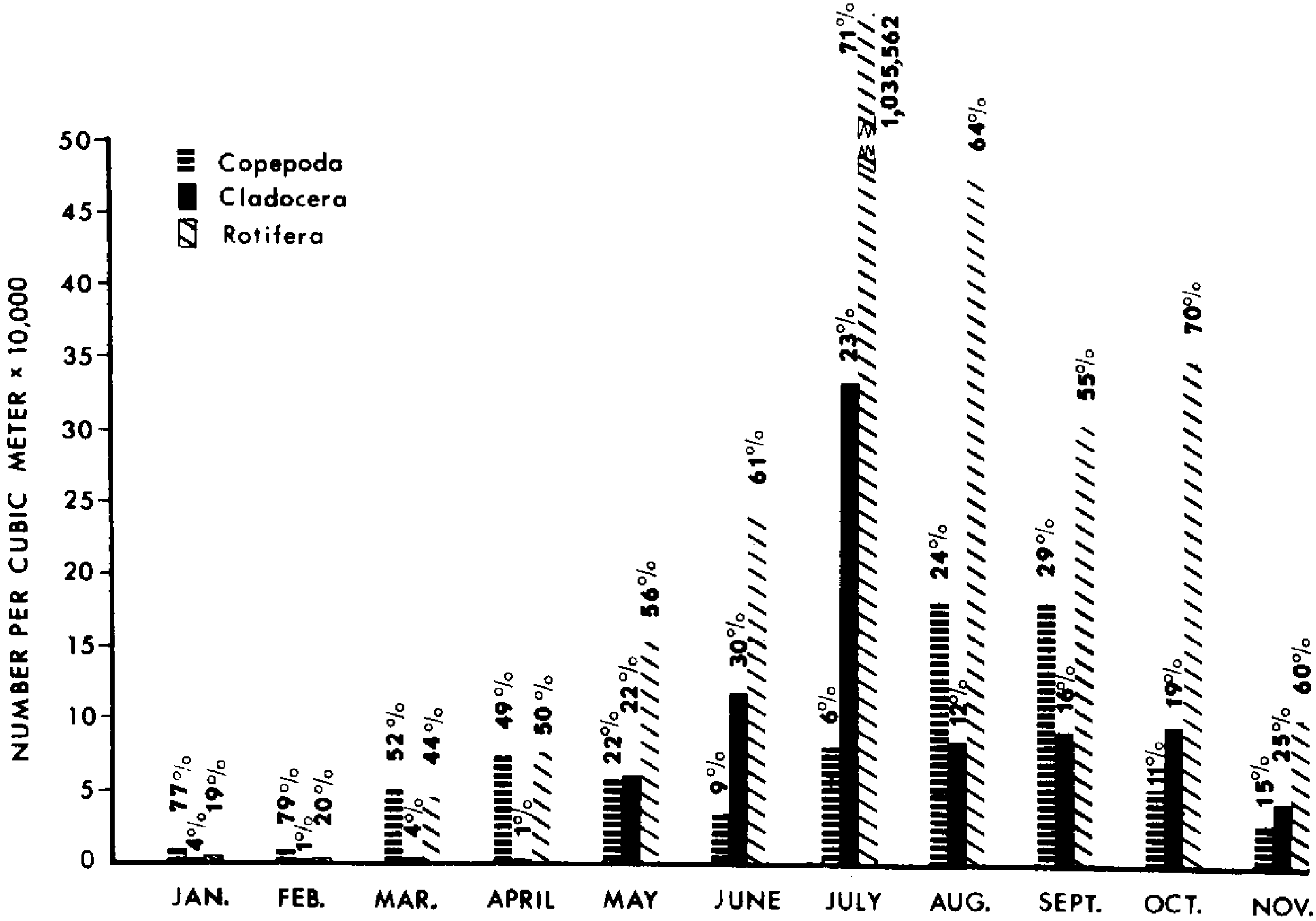


Figure 26. Average number of individuals for each major group of zooplankton per month (1973). This is an average of all stations sampled during the Pulliam Power Plant Study of lower Green Bay (Wisconsin Public Service Corporation, 1974).

3.3 ALGAE

a. Phytoplankton

The phytoplankton (floating algae) species composition of lower Green Bay was studied in detail in the year-long examination of the J. P. Pulliam Power Plant located at the mouth of the Fox River (Wisconsin Public Service Corporation, 1974).

This study showed that the freshwater phytoplankton cycle typical of the Temperate Zone occurs in Green Bay. The phytoplankton biomass reaches a spring peak dominated by diatoms and then decreases to a steady summer production level, based mainly on green and blue-green algae. In late August or early September, there is a lesser peak or bloom of greens and blue-greens before production gradually declines (see Table 18). The changing composition of the phytoplankton from spring to fall is reflected in the proportion of chlorophyll a to individual algae units. As the summer progresses, there is more chlorophyll a per individual unit due to the decline of single cell algae and the increase of filamentous units (Figure 27).

Of the 148 algae species identified in the Pulliam study, there were 80 diatoms, 49 green algae, 16 blue-green algae, 2 dinoflagellates and 1 euglenoid (see Table 19). Diatoms are a major component of the bay's phytoplankton community during winter and early spring months, comprising 100 percent of the population in those seasons. Five diatom species dominate the spring bloom. Three of these—*Asterionella formosa*, *Fragilaria capucina* and *Synura sp.*— reach their peaks in the spring and decline greatly afterward. The remaining two, *Stephanodiscus Hantzschii* and *Melosira granulata*, remain as part of the flora throughout the year. They share importance with the green algae *Actinastrum Hantzschii*, *Scenedesmus sp.* and *Pediastrum sp.* and the blue-green algae *Anabaena spiroides*, *Aphanizomenon flos-aque*, *Microcystis aeruginosa* and *Oscillatoria sp.* which become dominant during the summer months. It appears likely that the decline in diatoms that takes place in the spring is caused by the unavailability of sufficient soluble silica. Fogg (1966) noted that this was a common cause for diatom population crashes.

The dominance of green and blue-green algae during the summer months is probably caused by a complex of factors including increased water temperature, high light intensity and the availability of large quantities of essential nutrients.

Table 18. Average[1] Number of Units for Each Classification of Phytoplankton per Month. Samples taken from lower Green Bay, 1973.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
Chrysophyta	14.7	1601.1	11216.5	33108.5	3684.0	10300.9	7484.1	971.2	1500.8	622.4	477.8
Chlorophyta					129.3	904.4	1742.2	1366.8	629.8	1328.5	209.2
Cyanophyta					194.6	168.2	1287.2	521.1	177.4	286.7	41.7
Pyrrophyta								14.5	.7	.5	.2
TOTAL	14.7	1601.1	11216.5	33108.5	4007.9	11373.5	10513.5	2873.6	2308.7	2238.1	728.9

[1] All values are averages based on all sampling stations and are expressed as number of units/ml. from Wisconsin Public Service Corporation, 1974.

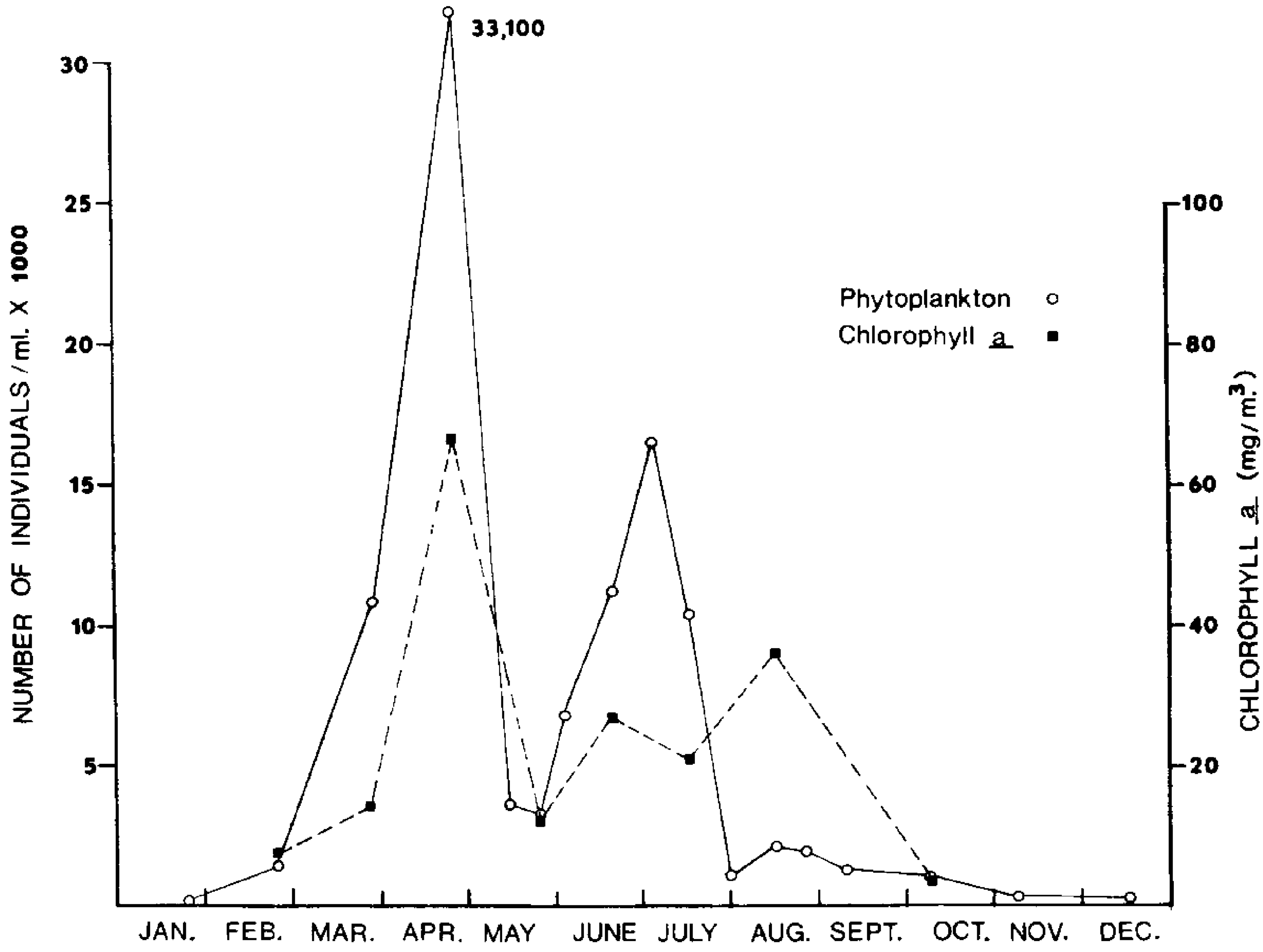


Figure 27. Total algal biomass as indicated by numbers of individuals/ml and chlorophyll a. Samples taken from lower Green Bay, 1973. From Wisconsin Public Service Corporation, 1974.

The spatial distribution of phytoplankton in lower and middle Green Bay (0 - 13.5 miles) was examined by Sager (1971) in a series of weekly samples. Sager distinguished two distinct phytoplankton communities, one associated with predominantly river water and the other with predominantly lake water. Samples taken at stations closest to the mouth of the Fox River were dominated by the green algae Melisora sp. and Anabaena spiroides. At the outermost, or lake water, stations, the dominant species were Stephanodiscus sp. and Oscillatoria sp. In the interface area between the river and lake communities, Oscillatoria was the dominant species, with Stephanodiscus also present.

Later in the summer, the blue-green algae Aphanizomenon flos-aque was particularly abundant at the outer stations. During this same period the inner stations were dominated by Melosira sp.

Sager found that the river and lake communities interfaced in the vicinity of Long Tail Point, approximately five miles from the mouth of the Fox River. River algal species predominated below this point and lake species above. This algal distribution generally corresponds to the circulation pattern of Fox River water in the lower bay that was described by Arhnsbrak and Ragotzkie (1970). Because Sager had no transverse sampling stations, it is unknown whether the river species he found also extended up the eastern shore of the bay, as might be expected. Sager also made a major distinction between the two community groups on the basis of phosphorous uptake.

The Pulliam Power Plant study included a larger number of sampling stations than Sager's study and described in more detail the variation in phytoplankton production within the lower bay. The investigators described this variation as a constantly changing mosaic in which algal blooms rise and disappear within the lower bay and in which various species predominate. The western shore of the bay, particularly, was found to be an ideal area for phytoplankton production. Not only is this section fed by nutrients from Duck Creek and the back waters of the Fox, but it is also a hydrodynamically dead area with little wave turbulence. Reduced turbidity and ample nutrients have increased the depth of the photic zone and allowed the accumulation of algae inside Long Tail Point.

Elsewhere in the bay, however, algae concentrations are short-lived due to prevailing winds and current patterns which break up and disperse any accumulations. The warm-weather algal bloom, generally noticeable on a more or less constant basis within Long Tail Point each summer, does not extend much beyond the Point. It is only occasionally found outside the 10-mile (16-kilometer) light. The rapid gradient of production in the area of Long Tail Point gives way to patchy blooms from Long Tail Point to the outer light and, very occasionally, beyond the outer light.

Schraufnagel et al. (1968) found no blooms beyond 40 miles (64 Km) from the mouth of the Fox River in 1966. Using chlorophyll a as a measure of algal biomass, Holland (1969) found an average of 10.4

micrograms chlorophyll a per liter from 20 to 30 miles (32 to 48 km) miles) from the mouth of the Fox River during the summer of 1965.

In the same region, the 1971 average for chlorophyll a was 18.6 micrograms per liter (Rousar and Beeton, 1973).

Sager (1971), sampling the bay from the mouth of the Fox to a distance of 40 miles (65 km) north, found an average of 21.9 micrograms per liter from June to August 1971. The value ranged from 1.2 to 57.4 micrograms per liter. Sampling for a longer period (June 1970 - October 1971) at the mouth of the Fox only, Sager found an average of 24 micrograms per liter of chlorophyll a. The values ranged from 0.2 to 80 micrograms per liter. Rousar and Beeton (1973), whose lower chlorophyll a value was 7.0, suggested that Sager's noticeably lesser values of 1.2 and 0.2 may have been due to differences in sampling techniques.

Sager (1971) found the highest concentration of chlorophyll a and plankton by dry weight at 1.5 to 5 miles (2.5 to 8 km) from the mouth of the Fox River. These steep gradients of chlorophyll a have been observed and confirmed in the vicinity of Long Tail Point for other physical and biological parameters. Sager found the lower bay inside Long Tail Point to be hypereutrophic and a perfect medium for the growth of phytoplankton.

b. Periphyton

Unlike the free-floating algae discussed above, periphyton are algal species which attach themselves to surfaces such as rocks and piers. Five species of periphyton were collected in lower Green Bay during the Pulliam Power Plant study (Wisconsin Public Service Corporation, 1974). Three species of green algae, *Cladophora glomerata*, *C. oligoclona* and *C. fracta*, and two species of blue-green algae, *Oscillatoria sp.* and *Phormidium sp.*, were taken in the vicinity of the power plant. *Cladophora glomerata* is the most common macrophytic algae in lower Green Bay and a common constituent of polluted hypereutrophic waters. This species was found to give way to blue-green algae at the higher water temperatures of the outfall but predominated elsewhere in the system.

Adams and Stone (1973) studied the in situ photosynthesis of *Cladophora glomerata* in lower Green Bay in the summer of 1971. Three study sites were selected: one inside Long Tail Point, the second inside Point Sable, and the third at Geano Beach in the middle Bay on the western shore, at a point 26.6 miles from the mouth of the Fox River. The most productive area in terms of net photosynthetic rates was the Point Sable station, with mid-day rates near 10 mg C .g-1 .hr-1. The Geano Beach station (No. 3) on the western shore had rates half this, and the Long Tail Point station was intermediate between the two in production. At the Point Sable station the photosynthetic rate changed from a relatively low 4-6 mgC.g-1.hr-1 in April and May to a maximum rate of 9-15 mgC.g-1.hr-1 from June to September. The study confirmed earlier findings that the growth of *Cladophora* is positively correlated with relatively high water

Table 19. Phytoplankton Species Recorded in Lower Green Bay During Pulliam Power Plant Study, 1973. (Wisconsin Public Service Corporation, 1974)

	Algal Reporting Unit[1]
CHRYSOPHYTA	
Achnanthes lanceolata Brebisson	(I)
Achnanthes minutissima Kutz.	(I)
Amphora ovalis Kutz.	(I)
Anomoeoneis sphaerophora (Ehr.) Pfitzer	(I)
Asterionella formosa Hass	(I)
Caloneis amphisbaena (Bory.) Cl.	(I)
Cocconeis diminuta Pant. (recorded by Sovereign)	(I)
Cocconeis pediculus Ehr.	(I)
Cocconeis placentula Ehr.	(I)
Coscinodiscus Rothii	(I)
Cyclotella comta (Ehr.) Kutz.	(I)
Cyclotella glomerata Bachmann	(I)
Cyclotella meneghiniana Kutz.	(I)
Cymatopleura solea (Breb.) W. Smith	(I)
Cymbella affinis	(I)
Cymbella prostrata (Berkeley) Cleve.	(I)
Cymbella sinuata	(I)
Cymbella ventricosa Kutz.	(I)
Diatoma elongatum (Lyngb.) Ag.	(I)
Diatoma hiemale (Roth) Heib	(I)
Diatoma vulgare Bory.	(I)
Epithemia sorex	(I)
Fragilaria brevistriata Grun.	(I)
Fragilaria capucina Desm.	(I)
Fragilaria construens (Ehr.) Grun.	(I)
Fragilaria crotonensis Kitton	(I)
Fragilaria intermedia Grun.	(I)
Fragilaria pinnata Ehr.	(I)
Gomphonema angustatum (Kutz.) Rabh.	(I)
Gomphonema olivaceum (Lyngb.) Kutz.	(I)
Gyrosigma kutzingii (Grun.) Cl.	(I)
Gyrosigma sciotense	(I)
Mastogloia braunii Grun.	(I)
Melosira Binderana Kutz.	(I)
Melosira granulata (Ehr.) Ralfs	(I)
Melosira islandica O. Mull	(I)
Meridion circulare (Grev.) Agardh.	(I)
Navicula americana Ehr.	(I)
Navicula bacillum Ehr.	(I)
Navicula canalis Patr.	(I)

[1] (I) counted as individual cells, (C) counted as colonies and (F) counted as filaments.

	Algal Reporting Unit[1]
Navicula confervacea (Kutz.) Grun.	(I)
Navicula cryptocephala Kutz.	(I)
Navicula cuspidata (Kutz.) Kutz.	(I)
Navicula exigua Greg. ex Grun.	(I)
Navicula gastrum (Ehr.) Kutz.	(I)
Navicula hungarica Grun.	(I)
Navicula peregrina (Ehr.) Kutz.	(I)
Navicula radiosa Kutz.	(I)
Navicula tripunctata (O.F. Mull.) Bory.	(I)
Navicula zanoni Hust. (recorded by Hohn and Hellerman, 1963)	(I)
Nitzschia amphibia	(I)
Nitzschia angustata (W. Smith) Grun.	(I)
Nitzschia apiculata (Gregory) Grun.	(I)
Nitzschia denticula	(I)
Nitzschia dissipata Grunow	(I)
Nitzschia filiformis	(I)
Nitzschia hungarica	(I)
Nitzschia larcunarum	(I)
Nitzschia linearis	(I)
Nitzschia palea (Kutz.) W. Smith	(I)
Nitzschia sigmoidea	(I)
Nitzschia tryblionella	(I)
Opephora martyi Herib	(I)
Rhoicosphenia curvata (Kutz.) Grun.	(I)
Staurastrum sp. Meyen	(I)
Stephanodiscus astrea (Ehr.) Grun.	(I)
Stephanodiscus Hantzschii Grun.	(I)
Stephanodiscus niagarae Ehr.	(I)
Stephanodiscus tenuis Schabitkowski	(I)
Surirella angustata Kuetzing	(I)
Surirella ovalis	(I)
Surirella ovata	(I)
Synedra acus Kutz.	(I)
Synedra nana (Meister)	(I)
Synedra parasitica (W. Sm.) Hust.	(I)
Synedra rumpens Kutz.	(I)
Synedra ulna (Nitzsch.) Ehr.	(I)
Synedra vaucheriae Kutz.	(I)
Synura sp.	(I)
Tabellaria fenestrata (Lyngb.) Kutz.	(I)
Unknown diatom	

CHLOROPHYTA

Actinastrum Hantzschii Lagerheim	(I)
Ankistrodesmus sp. Corda	(I)
Botryococcus Braunii Kuetzing	(C)
Cerasterias staurastroides West and West	(I)
Characium limneticum Lemmermann	(I)
Characium sp. A. Braun in Kuetzing	(I)
Chlorella vulgaris Beyerinck	(I)
Closteriopsis longissima Lemmermann	(I)

	Algal Reporting Unit[1]
Coelastrum microporum Naegeli in A. Braun	(C)
Coelastrum proboscideum Bohlin	(C)
Crucigenia irregularis Wille	(I)
Crucigenia quadrata Morren	(I)
Crucigenia rectangularis (A. Braun) Gay	(I)
Crucigenia tetrapedia (Kirch) West and West	(I)
Crucigenia truncata G. M. Smith	(I)
Dictyosphaerium sp. Naegeli	(C)
Franceia sp. Lemmermann	(I)
Gloeocystis major Gerneck ex. Lemmermann	(I)
Kirchneriella contorta (Schmidle) Bohlin	(I)
Lagerheimia sp. (DeToni) Chodat	(I)
Micractinium pusillum Fresenius	(C)
Oocystis sp. Naegeli in A. Braun	(I)
Pediastrum Boryanum (Turp.) Meneghini	(C)
Pediastrum duplex Meyen	(C)
Pediastrum sculptatum G. M. Smith	(C)
Pediastrum simplex (Meyen) Lemmermann	(C)
Pediastrum sp. Meyen	(C)
Planktosphaeria gelatinosa G. M. Smith	(I)
Scenedesmus acutiformis Schroeder	(I)
Scenedesmus armatus (Chod.) G. M. Smith	(I)
Scenedesmus bijuga (Turp.) Lagerheim	(I)
Scenedesmus dimorphus (Turp.) Kuetzing	(I)
Scenedesmus incrassatulus Bohlin	(I)
Scenedesmus longus Meyen	(I)
Scenedesmus opoliensis P. Richter	(I)
Scenedesmus quandricauda (Turp.) de Brebisson in de Brebisson and Godey	(I)
Selenastrum sp. Reinsch	(C)
Sphaerocystis Schroeteri Chodat	(I)
Tetraedron caudatum (Corda) Hansgirg	(I)
Tetraedron constrictum G. M. Smith	(I)
Tetraedron limneticum Borge	(I)
Tetraedron pusillum (Wallich) West and West	(I)
Tetraedron regulare Kuetzing	(I)
Tetraedron verrucosum G. M. Smith	(I)
Tetrastrum staurogeniaforme (Schroder) Lemmermann	(I)
Treubaria setigerum (Archer) G. M. Smith	(I)
Ulothrix zonata (Weber and Mohr) Kuetzing	(I)
Unknown greens	
Westella botryoides (W. West) de Wildemann	(I)
Westella linearis G. M. Smith	(I)

CYANOPHYTA

Anabaena spiroides Klebahn	(F)
Aphanizomenon flos-aque (L.) Ralfs	(F)
Aphanocapsa delicatissima West and West	(C)
Aphanocapsa endophytica G. M. Smith	(C)
Aphanocapsa sp. Naegeli	(C)
Aphanothece sp. Naegeli	(C)
Chroococcus dispersus (Keissl.) Lemmermann	(C)

	Algal Reporting Unit[1]
Chroococcus limneticus Lemmermann	(I)
Chroococcus minutus (Kuetz.) Naegeli	(I)
Coelosphaerium sp. Naegeli	(C)
Gloeocapsa aeruginosa (Carm.) Kuetzing	(I)
Gomphosphaeria lacustris Chodat	(C)
Marssoniella elegans Lemmermann	(C)
Merismopedia tenuissima Lemmermann	(C)
Microcystis aeruginosa Kuetz. emend. Elenkin	(C)
Oscillatoria sp. Vaucher	(F)
Unknown blue-greens	

PYRROPHYTA

Ceratium hirundinella (O. F. Muell.) Dujardin	(I)
Glenodinium sp. (Ehrenb.) Stein	(I)

EUGLENOPHYTA (Euglenoids)

Phacus sp. Dujardin	(I)

temperature and alkaline conditions. However, contrary to previous reports, it was found that *Cladophora* made efficient use of low illuminations. The elements nitrogen, calcium, strontium, sodium and zinc were concentrated by plants within Long Tail Point to a greater degree than those outside the influence of the Fox River plume. However, tissue analysis showed no difference in phosphorous among the three stations. The study indicates the complexity of natural growth rates and the importance and influence of nutrients on phytoplankton production within the bay.

3.4 SESTON

Mayhew (in Howmiller and Beeton eds., 1973) investigated the seston (suspended particulate matter) of the Green Bay area south of Sturgeon Bay. With some variation, the filtration samples were taken at depths of 2, 15, 30, 60, and 70 meters with either Van Dorn or Nansen bottles. Figure 28 gives the results at the two-meter depth in Green Bay. In general, the seston increased toward the mouth of the Fox River and toward the western shore. The latter unexplained finding is at variance with other water quality parameters that determine the cruise and expected distribution of particulates. The Green Bay seston concentrations are significantly greater than those measured in Lake Michigan.

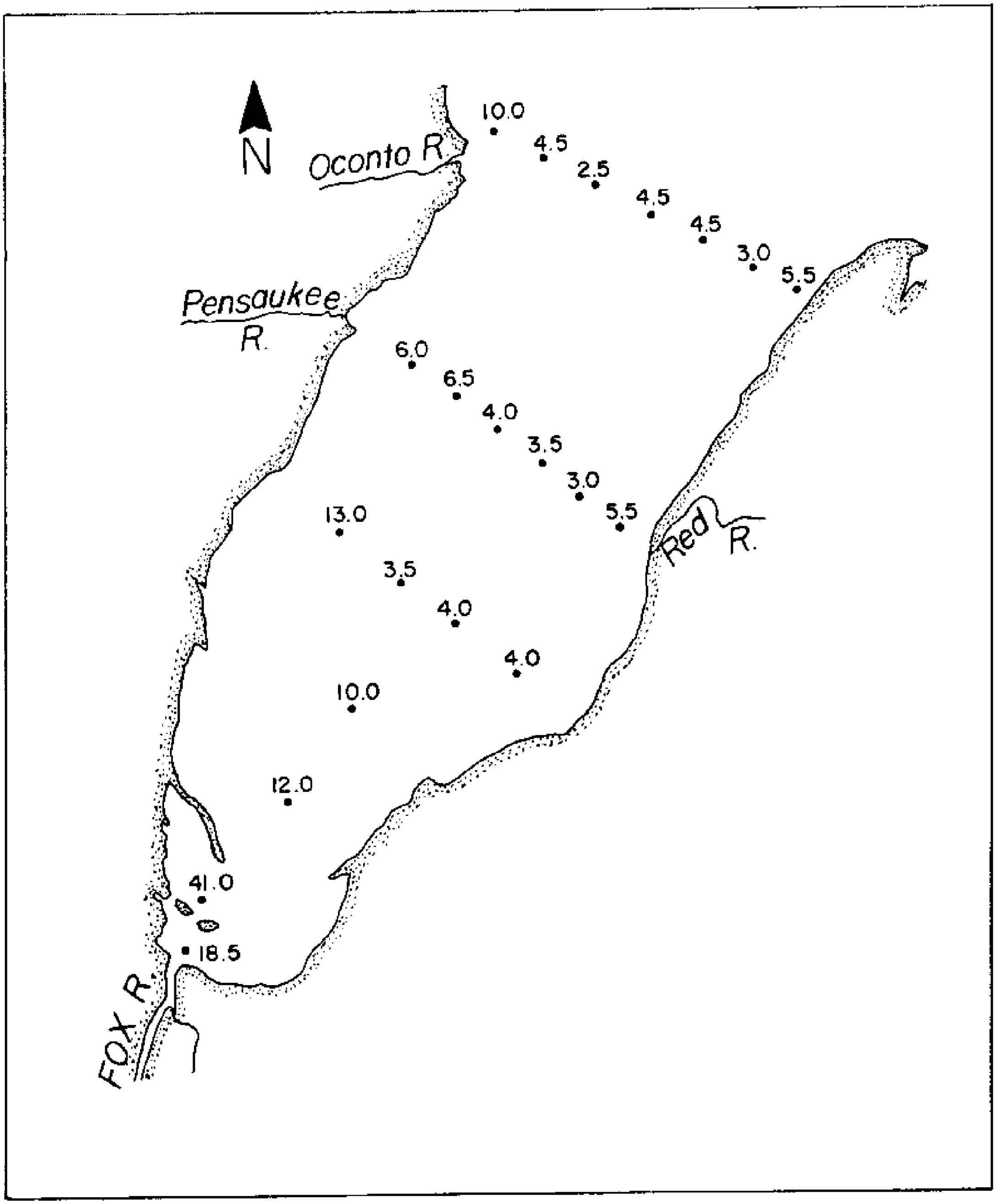


Figure 28. Green Bay Seston Concentrations (mg/liter) at 2 meters depth. From Mayhew, 1971.

3.5 THE LITTORAL ZONE

a. Composition and Distribution of Wetlands

The following discussion is based on information supplied by, and in part written by, Mr. Leroy J. Lintereur, a DNR game manager, who has spent the greater part of his professional life studying and managing the ecosystem of Green Bay's western shore.

If, as it has been said, the littoral is the most critical area of a body of water (Ketchum, 1972), then it can be said that Green Bay is currently in poor condition inasmuch as the littoral has drastically diminished. A decade ago, a broad band of emergent vegetation extended from the City of Green Bay to Escanaba, Michigan. Of varying width, (Figure 29) it extended from a matter of yards, to what seemed like the horizon and played host to a horde of waterfowl, aquatic birds and mammals, as well as a complex community of plankton and nekton. All this has vanished, at least temporarily, under the high water levels that have characterized the past years.

In sharp contrast to the high relief of Door County, the western shore is low, with vague indistinct shorelines that have fluctuated over a broad area, even in historic times. The shorelines of various glacial substages are still a matter of conjecture and finely delineated shorelines may not exist (Moore et al., 1973). But remnants of lacustrine conditions and vegetation can be easily found miles inland from the present shoreline.

The underlying geological formation of the western shore is Galena-Black River dolomite which does not outcrop as mantle rock anywhere in the west shore littoral (Moore et al., 1973). The overburden is composed of lacustrine sands with local deposits of recent clay or peat. The latter are relatively shallow and depths of over three feet are rare. This is in contrast to deep peat layers, 12 feet or more, found in Pleistocene Lake Oconto 35 miles inland. Shallow peat layers in the Green Bay littoral indicate the instability or youth of the bay.

As stated above, fluctuations in water levels and the resulting change in the area of the littoral are fundamental and conspicuous features of this zone. The fluctuations are reflected in the changing patterns of the aquatic vegetation associated with the shoreline. Vegetation of the littoral can be divided into recognizable subzones, each indicating particular environmental conditions. The following emergent species are readily identifiable since they occur in rather broad bands:

Band 1. *Scirpus validus* - The dominant emergent, this bulrush extends hundreds of yards into the lake in low water. It forms islands in some areas and comes inshore on wet sands. The species defines the outer limits of the littoral zone. Associated subdominants are the rushes, *Juncus bufonius* and *J. Balticus*.

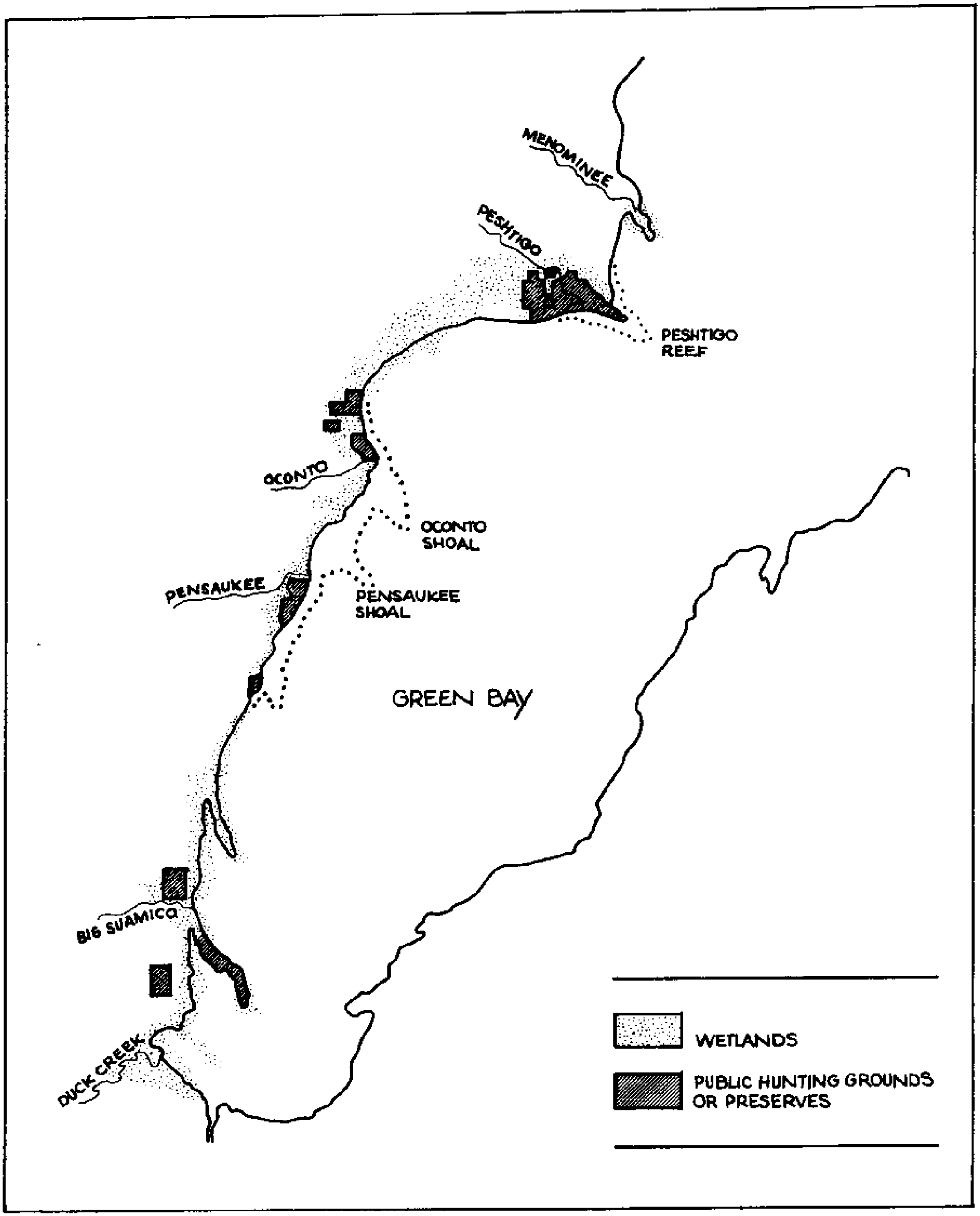


Figure 29. Wetland Areas on the Wisconsin West Shore of Green Bay.

Band 2. Scirpus americana - The dominant bulrush in wet sand areas (the psammolittoral), this species often forms pure stands and delineates a sharp zone. It is commonly associated with the subdominant sedges Carex lacustris, C. cryptolepis.

Band 3. Phalaris sp., (reed canary grass), Calamagrostis sp. (bluejoint) and Carex stricta (sedge) - Any of these three species in pure stands or associations tend to form meadows as well as relatively narrow bands. Associated with these species as subdominants are Gerardia eupatorial, G. perfoliatum, and G. urticifolium. Bidens sp. may form pure stands in mud.

Band 4. Salix fragilis (Willow) - In a legal if not a biological sense, this species delineates the inland boundary of the most shoreward zone. In periods of high water this band is subject to inundation. Dry land extending lakeward from this band is legally considered exposed lake bottom. Subdominant species in this band are Aster sp. (fall asters) and Solidago sp. (goldenrods).

These four stratified bands represent the ideal situation. There are numerous variations on the pattern of littoral vegetation along the coast from the City of Green Bay to Escanaba. In some areas, i.e., north of Oconto, the forest extends practically to the water's edge. In addition, there are at least four sizable pockets, literally bays within the bay, where all three outer zones are extended inward. On the western shore there are also three major reefs, Pensaukee, Peshtigo Point, and Longtail Point where the zone of emergent vegetation extends thousands of feet into the bay.

The current distribution of submergent vegetation on the bay's west shore is largely unknown. The best work on rooted aquatic vegetation of that area is found in Howlett (1974). Information indicates that in quiet waters, generally within reedbeds, Utricularia (bladderworts) and Anacharis (waterweeds) are common. The pondweed Potamogeton natans is also found in this zone. Other pondweeds, P. crispus and P. Richardsonii, seem to be ubiquitous. Wild celery, Vallisneria, forms pure stands locally, particularly on the reefs at Pensaukee and Peshtigo harbors.

b. Waterfowl

The littoral zone of Green Bay has historically been a major waterfowl breeding and feeding area in Wisconsin. The high water of the past years has depressed waterfowl numbers and disrupted their usual movements and feeding patterns. However, the general annual cycle can be described as follows:

The first migrating birds arrive immediately after the breakup of winter ice. The bay then harbors large rafts of scaup, redheads, widgeon, shovellors, and golden-eye ducks. Mallards, black ducks, common mergansers, buffle-head, canvasback, and ringnecks can also be found. Up to 15,000 ducks appear in the lower bay during April. Whistling swans arrive early and may be strung out along the entire length of the west shore. It isn't unusual to have a concentration of up to 3000 in the southern bay (USDI, 1968). The early waterfowl linger through the month of April.

Resident species of waterfowl include teal (both blue-wing and green-wing), mallard, and black ducks, in that order of abundance. Locally, widgeon and gadwall remain as nesting birds, and on the Oconto flowage, adjacent to the bay, there are nesting shovellers and occasionally scaup. Canada geese have bred on the Atkinson and Oconto marshes.

The shore zone is also a favored flight lane for shore birds. From the middle of May until well into June, huge flocks of these gather: dunlins, sanderlings, Baird's sandpiper, semi-palmated plovers and ruddy turnstones. Rarer are the dowitchers, godwits, stilt sandpipers, curlews and avocets. None of these birds nest in the area, although they may be present well into summer. The nesting shorebird species are spotted and solitary sandpipers and killdeer. There is a rookery of black-crowned night heron and great blue heron on Green Island, and birds from these rookeries commonly feed and roost in the shallow water.

Common and Caspian terns regularly migrate through this area, and there are records for little gulls on the lower reaches of the bay. Bonaparte's gulls and Forsters' terns are also migrants. The latter may nest on Oconto Marsh, although no nests have been reported. The only regularly nesting terns and gulls are the black tern and herring gull, the latter nesting along the full length of the bay and the former only on Grassy Island.

The fall migration is the reverse of the above, although it is complicated by the hunting season which tends to disperse the birds. The fall migration of swans, for instance, is more truncated than the spring flight. Shovellers are rarely seen, and the huge rafts that characterize spring activity are generally absent.

Blue-winged teal concentrate each fall and flocks of up to 10,000 may stay in the lower bay for several weeks (USDI, 1968).

The reefs off Green Island, Peshtigo Harbor and Pensaukee, which are vegetated by Vallesnaria, are favored by canvasbacks and there are times when these ducks may be seen there by the thousands. During the winter months the only birds in evidence are golden-eyes and mallards in areas of open water.

In addition to these typical water birds, the west shore littoral zone is used by a wide variety of terrestrial birdlife for feeding and resting during migration. Passeriform birds found in the littoral are those common to this type: red-wing blackbirds, long and shortbill marsh wrens, and locally, colonies of yellow headed blackbirds. The last named species has extended its range the full length of the bay in the past twenty years. In winter there is an occasional snowy owl as well as snow buntings which visit the area in flocks of thousands. Cleary (1972) has surveyed the bird fauna of Atkinson marsh near the city of Green Bay since 1940 and has recorded 196 species in this area up to 1972.

Fluctuating water levels are fundamental to the littoral zone and a normal element of its existence. Present levels, however, came up higher and faster than in the past and have stayed high for a longer period. The result has been a massive drowning of many emergent plants. With experts anticipating that the levels may go even higher (See discussion of flooding, p.109-119 .) there is concern that the littoral zone may be further diminished. Current levels have pushed the shallow waters that support dense aquatic vegetation shoreward. But in the flooded areas where cattails, reeds and other plants would normally be re-establishing themselves, there is extensive land fill activity going on. Since the last period of high water, the western shore of Green Bay has been largely developed for summer and permanent homesites. Homeowners are entitled to protect their properties and a number are doing so by dumping fill soil on low or flooded ground. This means that an important shallow section of the littoral is being eliminated in some areas.

The loss of the littoral zone in the bay is cause for major concern. Before the turn of the century there were approximately five million acres of wetlands in the State of Wisconsin; less than half remains today (USACE, 1975). Industrial pollution, land drainage and filling, and open water spoil disposal have been the destructive norm for the past one-hundred and fifty years. Wetlands provide numerous benefits to the maintenance of the health and stability of the ecosystem. The marshes of Green Bay provide spawning areas for fish such as northern pike and yellow perch. Other species use the littoral zone for various stages of their life cycle. The west shore littoral zone also provides high quality wildlife habitat. Muskrat and mink are common. Beaver and otter, heavily exploited by local trappers, can sometimes be found in substantial populations at the mouth of the Peshtigo River (Leroy Lintereur, per comm.). The littoral zone also serves as a buffer to heavy flooding, erosion, and storm damage by substantially dissipating the energy of the waves. The littoral may act as a sink for nutrients from sewage, farm runoff or industrial pollution by removing, detoxifying, or modifying these materials to reduce their harmful effects on the system. Conversely, the littoral may serve as a nutrient source as the shoreline vegetation dies back before the winter (Bently, 1969). The littoral also acts as a water clarifier, fine sediments being deposited in the quiet waters of the marsh.

There has been little quantitative work done on the precise role of the littoral zone in the maintenance of Green Bay's water quality. This is an important research need.

3.6 ENDANGERED SPECIES

The lake sturgeon, Acipenser fulvescens, is the largest fish in the Great Lakes, sometimes exceeding seven feet and 300 pounds. Its numbers have been greatly reduced in the Great Lakes over the last century. Although individuals are still occasionally caught in the Menominee and Fox Rivers (Don Olsen, per. comm.), annual catch has declined from 8.5 million pounds in 1885 to less than 3000 pounds presently.

The major cause of decline was overfishing by commercial fishermen late in the nineteenth century. However, stream pollution and the obstruction of access to spawning grounds were also important factors. The sturgeon must find a shallow lake or stream in which to lay its half million eggs. For many years, few Green Bay streams were in any condition to receive spawning sturgeon.

Because female sturgeon do not reach sexual maturity until they are twenty years of age, many large but young fish have been taken before they were ever able to reproduce. Current Wisconsin fishing regulations allow a seven week season in Green Bay and permit two sturgeon per licensed fisherman. The minimum length is 50 inches in the bay waters and 40 inches in inland waters. Lake sturgeon is considered a "managed species" by the Department of Natural Resources, but very little is actually known about the current status of the sturgeon in the bay fishery.

The lake sturgeon was included on the 1973 list of "Threatened Wildlife of the United States" (Bureau of Sport Fisheries and Wildlife, 1973). It will probably receive some protection under the Endangered Species Act of 1973 (Public Law 93-205).

Another Green Bay species of concern is the double-crested cormorant. Once commonly seen in the area, this species has now become very scarce. It disappeared from the area as a breeding bird for a number of years, although a colony was reported nesting on Grassy Island in 1974.

Other bird species which are being carefully watched by the Department of Natural Resources include Forsters' tern, the common tern, the yellow rail and the upland sandpiper. Though the piping plover has been lost from the bay as a breeding bird, it is still seen as a migrant and may again become established.

4. PHYSICAL AND CHEMICAL POLLUTANTS

4.1 PESTICIDES

The Green Bay drainage basin, particularly the fruit-growing area of Door County and the cultivated portions of the Fox and Wolf River watersheds, comprises a major agricultural area of Wisconsin. Thus it is not surprising that chlorinated hydrocarbon pesticides are widely distributed through the Green Bay ecosystem. In 1962, the estimated chlorinated pesticide use in the Green Bay watershed for households, industry and agriculture was 146,108 pounds (University of Wisconsin,1962). This total included 13,702 pounds of aldrin, 3,913 pounds of dieldrin, 977 pounds of endrin and 127,516 pounds of DDT. These four pesticides, plus lindane and heptachlor, comprised about 60% of the total pesticides used in agriculture in 1965 (Weaver et al., 1965).

Pesticides enter the aquatic system through surface run-off, groundwater flow, direct application or as atmospheric contaminants. The first survey of the sources and concentrations of pesticides in Green Bay was conducted by Johnson et. al. (1967) under the auspices of the Great Lakes-Illinois River Basins Project of the FWPCA (now EPA). Johnson et. al., analyzed the sources and concentrations in Green Bay of the pesticides lindane, heptachlor, aldrin, dieldrin, endrin and DDT. He found that the average concentrations of these pesticides in segments of the aquatic system varied seasonly (Table 20).

Table 20. Distribution of Chlorinated Hydrocarbons in the Green Bay Aquatic System

Date	Water ug/l	Muds ug/kg	Algae ug/kg	Soils ug/kg
Aug 17-18, 1966	0.005-0.03	5.0-37	19-166	11-7,878
Nov 30-Dec 1, 1966	0.012-0.123	146-1,538	---	---

From Johnson et al., 1967

Both DDT and endrin accumulated in algae in late summer and were then released to the water and bottom sediments in the fall (Figure 30). This pattern is characteristic of the behavior of all six pesticides studied. Pesticides were strongly concentrated in river muds each fall and winter. At the mouth of the Escanaba River, for example, the muds contained a DDT concentration two million times that of the surrounding water.

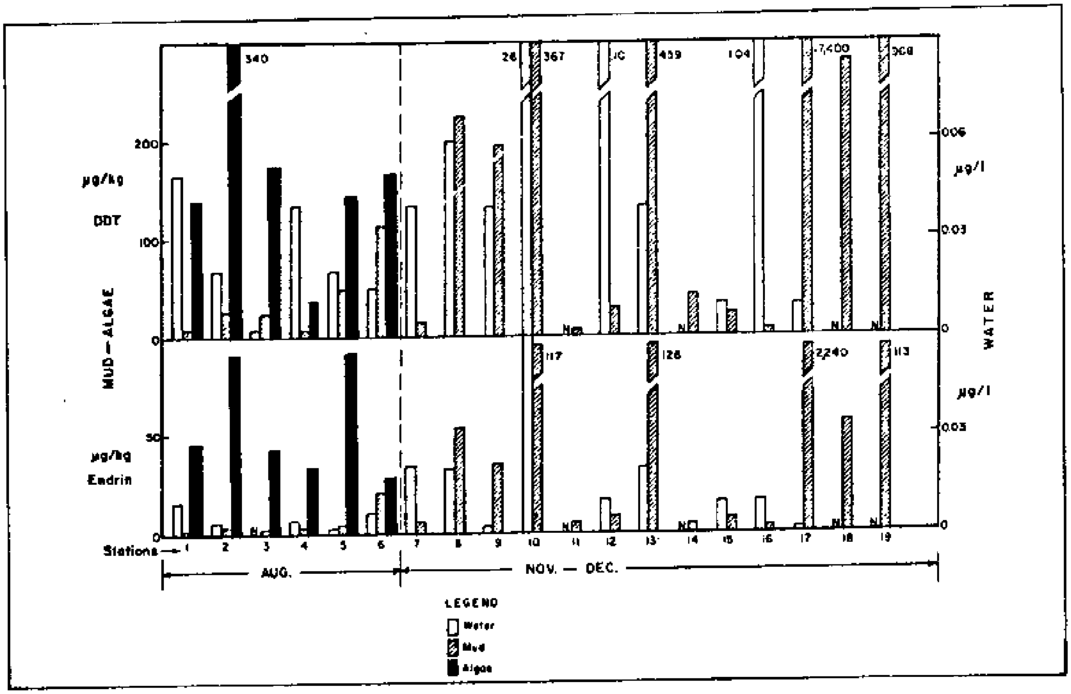


Figure 30. Seasonal Distribution of DDT and Endrin Through the Green Bay System, 1966 (Johnson et al., 1967)

Johnson et al., also showed that the type and amount of pesticides in Green Bay varied by district. Along the Door County shore, where a variety of fruit crops are grown, all six pesticides were found. Cedar River, in a forestry district, had concentrations of only dieldrin, endrin and DDT. In their average pesticide concentrations, Door County waters were five times higher than Cedar River waters. The study concluded that the upper bay had generally low pesticide loads, as did the entire bay, and pesticides did not pose a hazard to Green Bay's resources.

In spite of what appeared to be low pesticide concentrations in the bay's water and sediments, pesticides were accumulating in the bay's organisms at alarming levels. Hickey et al., (1965) surveyed the occurrence of DDT in Lake Michigan fishes on both sides of Door County. At that time, Door County's 10,000-acre cherry industry was using an estimated 30 tons of DDT and 15 tons of DDD annually. Hickey et al., found an average concentration of 3.3-3.4 ppm in alewives taken from gull stomachs. They also found levels of 2.28 to 7.87 ppm in chubs, and 5.05 to 7.49 ppm in muscle of whitefish caught in Green Bay. Animal species in almost all trophic levels of Lake Michigan had higher DDT residues than those found in Door County birds not connected to the lake's aquatic system (Hickey et al., 1966).

Keith (1966) suggested that DDT residues in Green Bay herring gulls were connected to a reduced hatching success of the gulls. Kleinert et al., (1968) found only traces of dieldrin in Green Bay fish but found a high level of DDT and analogs, 6.57 parts per million (ppm), in one rainbow trout from the middle bay near Door County.

Both Hickey's and Kleinert's studies suffer from a lack of adequate data on pesticide concentrations in Green Bay fish. However, their findings were sufficient to warrant continued monitoring of the pesticides.

In 1969 the Food and Drug Administration established an interim guideline of 5 ppm of DDT and its analogs as a safe level in foods and began seizing interstate commercial shipments of fish from Lake Michigan. Under these standards, 80% of Lake Michigan's commercial fish catch, valued at $2,816,000 in 1966, was unmarketable in interstate commerce. The impact of pesticides on the commercial fishery spurred on pesticide research and monitoring in Lake Michigan and Green Bay.

However, pesticide monitoring studies carried out between 1969 and 1971 showed considerable variation. Wisconsin Alumni Research Foundation, Inc., (WARF, 1970) surveyed the sediments of Green Bay tributary streams in July 1969. In the Menominee River sediments, total DDT ranged from 0.001 to 0.114 mg/l (or parts per million). Sediments from the Oconto and Peshtigo Rivers totaled 0.002 mg/l DDT. Michigan streams in the upper bay were also sampled and analyzed and only the Escanaba with 0.069 mg/l had significant DDT levels (WARF, 1970).

The Wisconsin DNR, in information supplied to the Environmental Protection Agency (US EPA, 1972), found 1970 DDT levels ranging from undetectable to 16 parts per trillion (16 ppt) in water samples 0.1 miles above the mouth of the Fox River. However, there was considerable evidence of polychlorinated biphenyl interference in the Fox River analysis. The DNR concluded that DDT concentrations in the Fox were probably less than 10 ppt DDT. In the same study, four samples taken from waters 0.2 miles above the mouth of the Menominee River had detectable but low levels of both dieldrin and DDT.

An EPA report of the pesticides in Lake Michigan (USEPA, 1972) suggests that the data variation between these studies is real and not a product of variation in techniques of analysis. Whether this is true or not, it is clear that the sampling problem is a major one. There is little reliable past data against which to measure present trends.

Although the emphasis of these pesticide studies has been on DDT, the importance of related pesticide compounds should not be underestimated. Aldrin is the most toxic of the commonly used persistent chlorinated hydrocarbon pesticides, and both aldrin and dieldrin are more toxic to mammals than DDT. Except for a few specified uses, DDT was prohibited by the EPA in 1972. In August 1974, the EPA extended this ban to aldrin and dieldrin because of known carcinogenic effects at low levels in rats. At the time these bans were imposed, larger trout and salmon in Lake Michigan, including Green Bay, generally exceeded the 5 ppm DDT set by the FDA, but not the 3 ppm dieldrin level (US EPA, 1972).

It is expected that the banned pesticides will decline in concentration in the environment. There is some unpublished evidence that DDT may breakdown more rapidly in lower Green Bay because of the anaerobic conditions (David Armstrong, University of Wisconsin-Madison, personal communication). Although it is expected that the moderate chlorinated pesticide levels found by Johnson et al., (1967) in Green Bay have decreased, there is currently no sampling program adequate to demonstrate this.

4.2 POLYCHLORINATED BIPHENYLS (PCBs)

Polychlorinated biphenyls (PCBs) are industrial plasticizing materials that have recently been recognized as serious contaminants in Green Bay and other waters of the Great Lakes. PCBs are chlorinated hydrocarbons chemically similar to the pesticide DDT. They were first introduced as insulating fluids in the 1930s. They are excellent plasticizers for paints and adhesives and provide fire-resistant electrical and hydraulic fluids. The sole American manufacturer is Monsanto Chemicals, Ltd. of St. Louis, Missouri. Under the trade name of "Aroclor," Monsanto markets seven complex mixtures ranging in chlorine content from 21 to 62 percent. Although Monsanto sales are now limited to important uses where the chemical cannot reach the environment, other nations continue to produce large quantities of PCBs and the compound now appears to have a ubiquitous distribution within natural systems. It has even been found in the eggs of Adelie penguins in Antarctica (Risebrough and Carmignani, 1971).

In 1969 Veith and Lee (1971) examined fresh trout and salmon from Lake Michigan and found PCBs in concentrations ranging from 10 to 25 micrograms per gram. These concentrations, higher than the levels then considered safe for human consumption, were in part responsible for the subsequent seizure of the Lake Michigan commercial fish catch by authorities.

The same authors (1971) reported PCBs in the sanitary wastes of all cities and villages they examined in the Milwaukee River watershed. Dube, Veith and Lee (1974) found that the effluent of six out of eleven sewage treatment plants examined in southeastern Wisconsin had PCB levels of 0.1 to 0.5 micrograms per liter. The Cedarburg Plant, examined in detail, removed 70% of the PCBs in processing.

PCB concentrations in the major Wisconsin rivers emptying into Green Bay were examined from December 1970 to August 1971 by Veith (1972). The analysis was conducted using gas and liquid chromatography. The results indicated that the Peshtigo, Oconto, and Fox Rivers had significant concentrations of PCBs while the Pensaukee and Big Suamico River had undetectable concentrations (Table 21). The concentrations appeared to

Table 21. Variations of Chlorobiphenyls in Rivers in the Green Bay Study Area

Rivers	Concentration (ug/l as Aroclor 1254)			
	12/29/70	5/21/71	7/20/71	8/6/71
Peshtigo River, Peshtigo	0.31	0.38	<0.01	<0.01
Oconto River, Oconto	0.45(3)	0.16	<0.01	<0.01(3)
Pensaukee River, Pensaukee	<0.01	<0.01	<0.01(1)	<0.01(1)
Big Suamico, Suamico	<0.01	<0.01	<0.01(1)	<0.01(1)
Fox River, Green Bay	0.18(3)	0.26	0.16	0.15

From Veith, 1972.

decrease over the course of the study. Although the Monsanto Company imposed a voluntary partial ban on the production of PCBs during this period, there was no relationship between the partial ban and the apparent decrease of PCBs in the river water. The decrease may have been a seasonal variation.

Reported concentrations of PCBs in the bay have varied from 0.07 micrograms per liter at Long Tail Point to 0.04 grams per liter approximately 35 miles northeast of the city of Green Bay. All PCB measurements must be regarded with some skepticism because of water sampling problems and the difficulties of accurately analyzing the chemicals. PCBs were not measured directly and, as Veith (1972) pointed out, explicit chemical confirmation was not possible. There was a distinct possibility of pesticide and chloronapthalene interference. The sampling error in replicate river water samples at 0.1 microgram liter level may have been up to 20% (Veith, 1972).

The acceptable limit on PCB concentrations currently set by the Federal Food and Drug Administration is 5 ppm. Sea Grant researcher David Armstrong of the UW Madison Department of Water Chemistry Laboratory (personal communication) believes this level may be too high. Primates fed a diet containing only 2.5 ppm of PCBs developed acne, hair loss, swollen eyelids and lips, enlarged livers, stomach ulcers and gastritis within one or two months. Additional unpublished Sea Grant research indicates the PCBs may be very persistent in the environment due to a slow natural degradation.

The problem of PCBs in Green Bay has not yet been adequately addressed. Their sources and current concentration in the bay and tributary streams are unknown. Because of the potentially significant effects of PCBs on human and ecosystem health, the problem needs thorough investigation.

4.3 HEAVY METALS

a. Sources

Heavy metal contaminants do not appear to be a major problem in Green Bay. This conclusion is based on the results of surveys of heavy metal sources in the region (primarily industrial manufacturers) and on the sampling of heavy metal levels in fish and shorebirds of Green Bay.

Konrad and Kleinert (1974) surveyed Wisconsin's large industries (50 or more employees), seeking voluntary information on industrial discharge rates of the metals arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc. (As of March 1, 1974 Wisconsin Statute 144-54 requires that industries report the discharge by kind and concentration of environmental pollutants including heavy metals.)

Ninety-eight percent of the 278 industries contacted responded. The combined annual reported discharge for heavy metals in the Fox River Valley, Marinette, and Peshtigo areas was 9,115 pounds per year to the air, water and soil. This total annual poundage was far below that found in the state's major metal-working regions such as the Racine-Kenosha area which reported 324,170 pounds per year (Table 22).

Table 22. Annual Poundage of Metal Wastes Discharged to the Air, Water and Soil in Selected Areas

	Annual Poundage Discharged to the Air, Water, and Soil							
Metal	Milwaukee Area	Racine Kenosha Area	Fox River Valley Marinette Peshtigo	Central Wisconsin Area	Grafton Mayville Horicon Beaver Dam Hartford Ripon Fond du Lac	Madison Janesville Beloit Lake Mills	Sheboygan Kohler Manitowoc Two Rivers	La Crosse Sparta
Arsenic	–	–	1,800	530	–	–	–	–
Beryllium	50	–	–	–	–	–	–	–
Cadmium	• 754	–	30	–	4,743	30	–	–
Chromium	19,460	31,777	3,360	1,591	3,516	3,680	8,430	17,000
Copper	6,688	74,099	3,820	2,150	870	197	405	2,210
Lead	2,500	117,965	–	380	–	–	861	345
Mercury	–	–	–	29	–	–	–	90
Nickel	22,933	3,214	50	3,038	615	435	–	8,450
Selenium	–	–	–	5,907	–	–	–	–
Zinc	64,443	97,115	55	58,007	8,875	610	10,145	81
Total	116,828	324,170	9,115	71,632	18,619	4,952	19,841	28,176

From Konrad and Kleinert, 1974

Besides direct industrial discharge, heavy metals reach the bay via municipal sewage treatment plants, surface runoff and atmospheric dust. Konrad and Kleinert (1974) in a survey of 35 Wisconsin sewage plants found that the plants varied widely in their removal of heavy metals. In general, they found that mercury removal improved from 14 percent with primary treatment to 69 percent with secondary treatment. Lead removal also rose from 38 percent with primary treatment to 51 percent with secondary treatment. The Green Bay Metropolitan Sewage District plant removed 20 percent of the lead (0.20 mg/l to 0.16 mg/l) and just over 20 percent of the mercury (0.0007 mg/l to 0.0005 mg/l). The Menominee sewage plant showed no detectable influent-effluent change in either lead or mercury concentration.

It is generally accepted that lead pollution of surface waters comes from atmospheric sources (Shimp et al.,1970; Lazrus et al.,1970). The Pulliam Power Plant study (1974) found that concentrations in lower Green Bay are higher nearer to the city of Green Bay, the presumed source of the pollution being vehicle and industrial exhaust.

Regardless of how the metals enter the bay,they are ultimately buried in bottom sediments from whence they are continually released to the water column and the food chain. The Pulliam Power Plant study (1974) suggested that the Fox River is a source of copper, zinc, cadmium, chromium and mercury. Concentrations of these metals in the sediments of the lower Fox River are constantly being disturbed and dispersed into the lower bay. Konrad (1971) found that mercury deposits still existed in Green Bay sediments even though industrial use of mercury had declined. Although the metal was immobilized in the sediments, Konrad speculated that it would continue to escape to the water column as the sediments were disturbed by dredging or were eroded. The Pulliam study (1974) confirmed that mercury concentrations in the sediments of the lower Fox River and Green Bay were significantly higher than background levels and higher than levels in Lake Michigan.

However, the Pulliam study found that other heavy metal concentrations in lower Green Bay sediments were comparable to or less than levels in Lake Michigan (Table 23). Sub-surface glacial clays were much lower in heavy metals indicating the recent nature of surficial metal deposition in the bay. Lead concentrations in the lower bay were less than in southern Lake Michigan and were not unusually high. Nickel concentrations approached the levels found in subsurface glacial clays and indicate little nickel deposition from industrial or municipal sources.

The Pulliam study revealed that the deposition of heavy metals (particularly copper, zinc, mercury and chromium) and their release from the sediments could be locally influenced by a power plant. First, the jet plume from the plant, although not in direct contact with the bottom sediments, prevents additional metal deposition. Thus there is an area in the immediate vicinity of the plant with lower metal concentrations. The second and more significant factor is the effect of the power plant's waste heat on metal sorption. Increasing temperature decreases the amounts of metals sorbed to the sediments and increases the amounts of metals in the water column that are available for biological concentration. The net result is more heavy metals in the water and less in the sediments. The significance of this latter phenomenon for the health of the aquatic food chain was not discussed, but it is probably low since the area of bay affected is low.

Table 23. Ranges of Heavy Metal Concentrations (ug/g) in Green Bay and Lake Michigan Sediments (Wisconsin Public Service Corporation, 1974)

	Cu	Zn	Cd	Pb	Cr	Ni	Hg
Lower Fox River (present study)	1-02	7-204	0.6-3.4	NA	6-128	3-24	0.06-3.48
Lower Green Bay (present study)	1-66	4-111	0.2-2.7	2-38	3-69	1-23	0.03-2.72
*Surface Sediments (Lake Michigan)	9-75	58-519	NA	27-172	35-165	18-58	0.06-0.38
*Baseline (Lake Michigan)	15-30	50-100	NA	15-30	20-40	15-40	0.05-0.10
Glacial Clay	18	35	1.9	NA	36	24	NA

*Frye and Shrimp, 1973

NA--not analyzed

b. Mercury Levels in the Food Chain

A prime source of mercury to Green Bay, before pollution abatement measures were taken, was the pulp and paper industry. Westoo (1969) found that high levels of mercury in fish could generally be correlated with levels of wastes from pulp and paper mills using mercury compounds and from chlorine-caustic soda plants employing mercury cell processes. Bligh (1971) found this to be true for Canadian fish. In the Green Bay area, as of 1972, there were 23 operating paper mills, 19 on the Lower Fox, 2 on the Menominee, 1 on the Peshtigo, and 1 on the Wolf. Alkaline conditions and mercury deposits have been identified on the Fox, Menominee, and Wolf Rivers (Konrad, 1971).

The FDA decision of 1958 specifying that food wrapping be free of mercury greatly reduced the use of these compounds in paper manufacture. Subsequent DNR orders in 1970 regulated the amount of organic and inorganic mercury in effluent discharge and designated those alkyl mercury compounds used in seed storage as pesticides. Both of these measures diminished the discharge of mercury in Wisconsin.

Table 24. Mercury Levels in Fish Fillets from Green Bay Watershed

Fish Collection Description				ppm Mercury		
County & Water	Site	Date	Species Sampled*	Low	Avg.	High
FOX-WOLF RIVER DRAINAGE						
Fond du Lac, Fond du Lac River	River Mouth	4/27/70	S	-	.20	-
Shawano, Wolf River	Above Shawano	8/6/70	2R, B, CR	.16	.27	.47
Shawano, Wolf River	Below Shawano	8/6/70	2R, 2D	.44	.64	.89
Winnebago, Lake Winnebago	Asylum Bay	4/23/70	5D, 6CR, 2NP	.01	.17	.37
Brown, Fox River	River Mouth	5/6/70	S, D, 3C, 2W, 2WB	.11	.36	1.92
Brown, Fox River	River Mouth	4/27/70	YP	-	.26	-
GREEN BAY						
Brown, Green Bay	East of Fox River Mouth	8/5/70	8C, NP, BU, YP, W	.06	.21	.37
Door, Green Bay	North of Sturgeon Bay Canal	6/5/70	S, BF, A, 4CI, 3LT	.19	.30	.45
Oconto, Green Bay	East of Oconto	6/12/70	5S, SMB, B, CR, 2NP 2BU, YP, 2W, 2BR	.90	.36	.75
	East of Oconto	10/15/70	3S, 3C, 2SMB, 3CR, 2P, 4NP, 2BU, 3BR, 3LT, 3CS, 2WB	.05	.26	.46
Marinette, Green Bay	East of Marinette	10/26/70	4S, 3C, 4NP, 2BU 4BR, 3RT, 3LT, 3CS, 2WB, 2L	.01	.26	.56

*Fish species
A--Alewive
B--Bluegill
BF--Buffalo
BR--Brown Trout
CR--Crappie
CS--Coho Salmon
D--Freshwater Drum
L-Burbot
LT--Lake Trout
NP--Northern Pike
P--Pumpkinseed
R--Redhorse
S--Sucker
SMB--Small Mouth Bass
W--Walleye
WB--White Bass

Mercury levels in Wisconsin fish have been surveyed in some detail (Kleinert and Degurse, 1972). Mercury determinations were made for 1,824 fish fillets from 36+ species. Thirty-four percent of the species sampled were classified as roughfish and 66 percent as gamefish. All of the fish analyzed contained a detectable level of mercury. In Green Bay the average mercury level was 0.27 ppm with a range from 0.01 to 0.75 ppm (Table 24). The average mercury concentration for fish from the Menominee River was somewhat higher at 0.43 ppm with a range of 0.06 to 1.72 ppm.

The Food and Drug Administration bans those fish from interstate sale that have mercury levels of 0.5 ppm or more. In Wisconsin, fishermen are advised to limit their fish consumption to no more than one meal a week if the fish are taken from waters whose fish show an average mercury level of more than 0.5 ppm. No waters in the Green Bay watershed currently carry this warning, although fish taken from the Wolf River averaged 0.64 ppm mercury.

Mercury levels in wildlife other than fish were also surveyed by Kleinert and Degurse (1972). Mercury contents were generally found to be at or below the FDA safe level of 0.5 ppm, but diving ducks, herons and grebes approached or exceeded the FDA standard. One blue-winged teal from Atkinson Marsh in Green Bay contained 1.62 ppm mercury. Few general conclusions can be drawn from the wildlife survey because of the inadequacy of the sample and uncertainty concerning the mercury uptake and rate of concentration in wildlife. Different species concentrate mercury differentially. Diet, age and physical condition appear to play an important role (Bligh, 1971).

The Pulliam Power Plant study (1974) found that mercury concentrations in the lower Fox River and Green Bay sediments were significantly higher than background levels or the levels found in Lake Michigan. They also found that mercury levels in five sample of midge larvae (Chironomidae) which live on the bottom sediments ranged from 0.05 to 0.12 micrograms mercury per gram by wet weight and 0.38 to 0.888 micrograms per gram by dry weight.

c. Lead, Arsenic and Other Heavy Metals in the Food Chain

Kleinert, Degurse and Ruhland (1974) of the Wisconsin Department of Natural Resources analyzed 224 fish samples collected from state waters for lead, arsenic, cadmium, chromium and zinc content (Table 25). The detection limits of the DNR survey were 0.05 ppm for cadmium, zinc and lead; 0.03 ppm for chromium; and 0.1 ppm for arsenic. The US Food and Drug Administration has set no standards for concentration of these five metals in fish products.

Table 25. Arsenic, Cadmium, Chromium, Lead and Zinc Levels in Fish from Wisconsin Waters*

		Sample #	Species	Length (Inches)	Metal Levels in ppm Cr	Zn	Cd	As	Pb
Water	Green Bay	1,193	Carp	16.0	-	-	0	-	0.44
County	Brown	1,194	Carp	16.0	-	-	0	-	0.46
Site	E. of Fox R. Mouth	1,195	Carp	16.0	-	-	0	-	0.27
Date	5 Aug 1970	1,191	Carp	18.0	0.07	8.8	-	-	-
		1,190	Carp	30.0	0.27	7.1	-	-	-
Water	Green Bay								
County	Door								
Site	N. of Sturgeon Bay Canal								
Date	5 Jun 1970	358	5 Sucker	14.7-18.5	-	-	-	-	0.12
		360	Lake Alewife	6.7-9.5	-	-	0	-	0.12
		363	Cisco	16.0	0	3.7	-	0.10	-
		359	3 Burbot	20.0-28.8	0	5.1	-	0.10	-
		356	Lake Trout	26.0	-	-	-	-	0.11
		355	Lake Trout	28.5	-	-	-	0.35	-
Water	Menominee River	182	2 Sucker	14.0-18.0	-	-	0	-	0.07
County	Marinette	66	2 Sucker	20.0	-	-	0	-	0.18
Site	River Mouth	181	3 Bullheads	8.8-9.1	-	-	0	-	0.05
Date	20 May 1970 and 15 Jun 1970	69	3 Bullheads	8.5-10.0	-	-	0	-	0.05
		214	2 Sunfish	7.0	0.04	5.7	-	0	-
		176	Sunfish	7.5	0	4.8	-	-	-
		215	Largemouth Bass	14.5	0	3.7	-	0	-
		185	Largemouth Bass	16.0	0	4.1	-	0.12	-

*From: Kleinert, Degurse and Ruhland (1974).

Lead was detected in 102 of the 115 samples tested. Although the USFDA has not set standards, the Canadian Food and Drug Directorate has set 10 ppm as the maximum allowable in animal products (Mount et al., 1970). All fish tested from Green Bay waters by Kleinert et al., 1974, had detectable lead levels which averaged 0.19 ppm and ranged from 0.05 to 0.46 ppm. Most other Wisconsin watersheds had higher average lead concentrations than Green Bay.

Arsenic was found in 29 of the 95 state samples tested and in four of the six tested from Green Bay waters. The USFDA has established a standard of 2 ppm of arsenic for chicken and turkey innards although no standard has been set for fish. The highest Wisconsin sample was one Green Bay lake trout with an arsenic concentration of 0.35 ppm. Konrad and Kleinert (1974) in their survey of industrial heavy metal sources noted that almost 20 percent (1800 lbs.) of total Green Bay area heavy metal discharge was arsenic in water effluent. Konrad and Kleinert did not discuss the source or fate of this discharge.

Kleinert et al.'s fish survey showed no detectable cadmium concentration in Wisconsin fish. Levels as high as 0.3 ppm had previously been found in Michigan samples by Hesse and Evans (1972). Chromium was found in 61 of 97 samples tested for Wisconsin and in 4 of 7 samples from the Green Bay watershed. Zinc was present in all samples tested. The average concentration of zinc in Green Bay waters was 5.4 ppm which is below the range of 6 to 45 ppm reported for Michigan fish (Hesse and Evans, 1972). This was not appreciably different from earlier reports by Walters et al., (1972) and Sayers et al., (1973).

Kleinert et al.,(1974) pointed out that their survey is only a starting point for further analysis. The difficulties of sample size, ages, and condition of the fish, and time of the year all conspired to make meaningful comparison and evaluation of the limited data difficult if not impossible. They recommended continued studies to determine what if any correlations exist between the concentrations of heavy metals in fish and in their environment.

4.4 WASTE HEAT

A report by the Great Lakes Fishery Laboratory (USDI, 1970) predicted that the future health of Lake Michigan's coastal waters could be seriously impaired by potentially high additions of waste heat into the system from proposed shoreline power plants. The most significant impact was expected to occur in the near shore area where the heat would be largely confined.

Thermal pollution in Green Bay, however, does not appear to be a problem at present (USDI, 1970). Green Bay has only one major power plant, the J.P. Pulliam Plant located at the mouth of the Fox River in the city of Green Bay. The plant has a nominal capacity of 392.5 megawatts with a maximum capacity of 439 megawatts. It contains eight coal-burning generating units and in 1973 received by ship 950,000 tons of coal. The plant is water cooled and in 1973 used 337,000 gallons of water per day, a rate of 521 cubic feet per second.

The nature of the Pulliam plant's thermal effluent and its effects on the lower bay's biota and physical properties were investigated from January to December 1973 by the staff of the University of Wisconsin-Green Bay (Wisconsin Public Service Corporation, 1974). The study area was within Long Tail Point and Point Au Sable 20 square miles (or 32 km).

A 2°C thermal plume was found to extend about 0.5 miles (800 m) into Green Bay. At times the surface plume extended across the mouth of the river. Surface plumes of 1°C above ambient temperature were found covering areas of from six to seventy acres. Turbulent entrainment provided mixing at the effluent jet while wind and wave action completed the local mixing process. Sedimentation rates were only locally effected by the plant.

Generally little change was found in water quality in the vicinity of the plant. The exception was a locally increased availability of heavy metals for incorporation into the food chain. This was due to slightly higher water temperature, caused by the plant outfall, which decreased the amounts of heavy metals sorbed to sediments and increased the amounts of metal in the water column.

There was some evidence that in-plant chlorination locally reduced the fecal coliform count in the plume area. However, overall, bacterial counts in the study area were high, decreasing with distance from the Fox. Beyond 6000 meters from the plant, there was often a zero fecal coliform count but samples near the river mouth ranged from 100 to 1,000,000 per 100 ml sample.

Numbers of phytoplankton and zooplankton did increase within the thermal plume during the winter months. But since the area of greatest plankton productivity is on the west shore out of direct influence of the thermal plume, the plume appeared to have little discernible effect on phytoplankton or zooplankton productivity or on periphyton distribution. Benthos likewise appeared to be unaffected by the thermal plume which rarely reached the bay bottom.

The plant appeared to have minimal or insignificant effects on the water passing through it. Water enters the plant from the Fox River and Green Bay in a seriously degraded condition and comes out in the same state. At no time was there a significant decrease in the dissolved oxygen concentration of water as it passed through the condensers, although the Fox River intake often provided water with zero oxygen to the plant during summer months. Neither were there significant ionic changes or major changes in total and organic carbon, color, soluble silica or pH.

In general, it was concluded that any ecological effects caused by the plant's waste heat could not be isolated from the myriad effects of the Fox River and its creation of a hypereutrophic system. Given the present river conditions and present size of the plant, there appear to be "no present major deleterious effects" on Green Bay. Long term effects and possible future effects of plant expansion were not discussed, but the Pulliam study provides some baseline information.

4.5 DREDGING AND SPOILS DISPOSAL

a. Current Practices

Dredging and spoil disposal are activities of some concern in Green Bay because of their potential environmental impacts on the bay ecosystem. Dredging consists of either "new work" or "maintenance work." New work involves the scooping or cutting and removal of previously undisturbed sediment or bedrock. Maintenance is the removal of sediments which have settled into a previously cut channel (U.S. Army Corps of Engineers, 1969). These sediments are often light and shifting and easily removed.

Until 1970, dredging spoils were generally dumped in some designated open water site, not too distant from the harbor or channel being dredged. However, with the passage of the River and Harbor Act of 1970 (P.L. 91-611), the U.S. Army Corps of Engineers, the agency in charge of dredging was authorized to construct contained disposal sites. These sites were to receive all dredgings that were polluted with pesticides, heavy metals, and other toxic materials (U.S. Army Corps of Engineers, 1972). Prior to the 1970 act, the Corps had already begun an assessment of alternative spoil disposal methods and sites. The Corps engaged the Water Resources Center of the University of Illinois to study potential benefits that would follow from contained rather than open water disposal of polluted spoils in the Great Lakes. The Water Resources Center findings are summarized as follows (U.S. Army Corps of Engineers, 1969a):

> Benefits to municipal water supply—benefits in the form of savings in chemicals and other treatment processes for the water supply of Chicago would amount to $7,500 annually. Since the total 1967 cost of chemicals and water treatment in Chicago was $2,466,347, the savings was relatively insignificant.
>
> Benefits to industrial water supply—since water quality is most important in the relatively small volume used for boiler feed or in the amounts used for actual material processing, it was assumed that industrial water supply benefits would be similar to municipal water supply—that is, insignificant.
>
> Benefits to recreation—while only very slight improvements in water quality are expected in open water disposal areas, changes —negative or positive—will be more noticeable in near shore areas where alternate disposal practices are used. But even slight improvements in shoreline areas could result in sizeable benefits.
>
> Benefits to commercial fishing—the benefits cannot be calculated until more is known about the ecology of the Great Lakes.
>
> Benefits that are intangible—if the knowledge of open-water dumping, regardless of its impacts on water quality, detracts from an areas' appeal to tourists or other users, this is an intangible loss.

Although these findings showed that the immediate economic benefits of contained disposal were minimal, unknown or unmeasurable, the Corp determined that contained disposal was a positive step toward improved water quality in Great Lakes harbors. A 1967 survey by the Corp had shown that sediments from a number of Great Lakes harbors were seriously polluted (U.S. Corps of Engineers, 1969).

b. Federal Dredging Projects on Green Bay

The Corps' 1967 analysis of dredge spoils from selected Great Lakes harbors included the harbor and ship channel of Green Bay (U.S. Army Corps of Engineers, 1969). Green Bay city harbor is the enlarged and excavated mouth of the Fox River. It is connected to the deeper parts of the bay by an 11-mile channel across the shallow inshore areas. The bulk of sediments deposited in the harbor area are from the Fox River watershed. However, in the outer channel, older, shifting lake bottom materials are the main source of sediment.

Not surprisingly, the dredgings from the mouth of the Fox River and the inner ship channel contained highly polluted sediments (Table 26).

Table 26. Composition of Sediments at Green Bay, Wisconsin

Parameter	Fox River[b]	Green Bay[b]	Green Bay[c]
% Total Solids	25.3	24.8	29.91
% Volatile Solids	18.4	17.8	46.72
COD	219	215	251.8
Phosphorus-Total	4.37	3.35	0.35
Phosphorus-Soluble	1.02	0.6	-
N-Total	5.34	6.89	-
$N-NH_3$	0.63	0.47	0.55
N-Organic	4.7	6.4	6.34
Phenol	0.004	0.003	0.014
Oil and grease	32	15	6.88
Sulfide	0.68	0.37	0.23

[a]All values are averages and in mg/g (dry weight) except where noted.
[b]FWPCA 1967 data
[c]FWPCA 1968 data, one sample only

From Dredging and Water Quality Problems in the Great Lakes., Vol. 1, Summary Report, U.S. Army Corps of Engineers, 1969.

Several possible disposal sites for Green Bay harbor's polluted sediments were considered (Figure 31), including the present site, Atkinson Marsh (Site No. 5). At the time of the Corps study, Atkinson marsh was being developed into a 400-acre diked disposal area to make filled land. With the cooperation of the city and the Corps the dike was built from the new work dredgings of 1966 and 1967. The city expressed the desire at that time to accept no new maintenance dredgings in the fill area after 1969. Consequently, 1967 and 1968 maintenance dredgings were deposited in a sump area offshore from the dike and were inteded to be transferred by hydraulic dredge into the dike at a future date.

After 1969, no new materials were added to the sump. It was completely cleaned out and all materials were transferred to the marsh in the summer of 1974 (per. comm., Chicago District Office, U.S. Army Corps of Engineers). In addition, 1973 and 1974 dredgings have been put directly into the marsh.

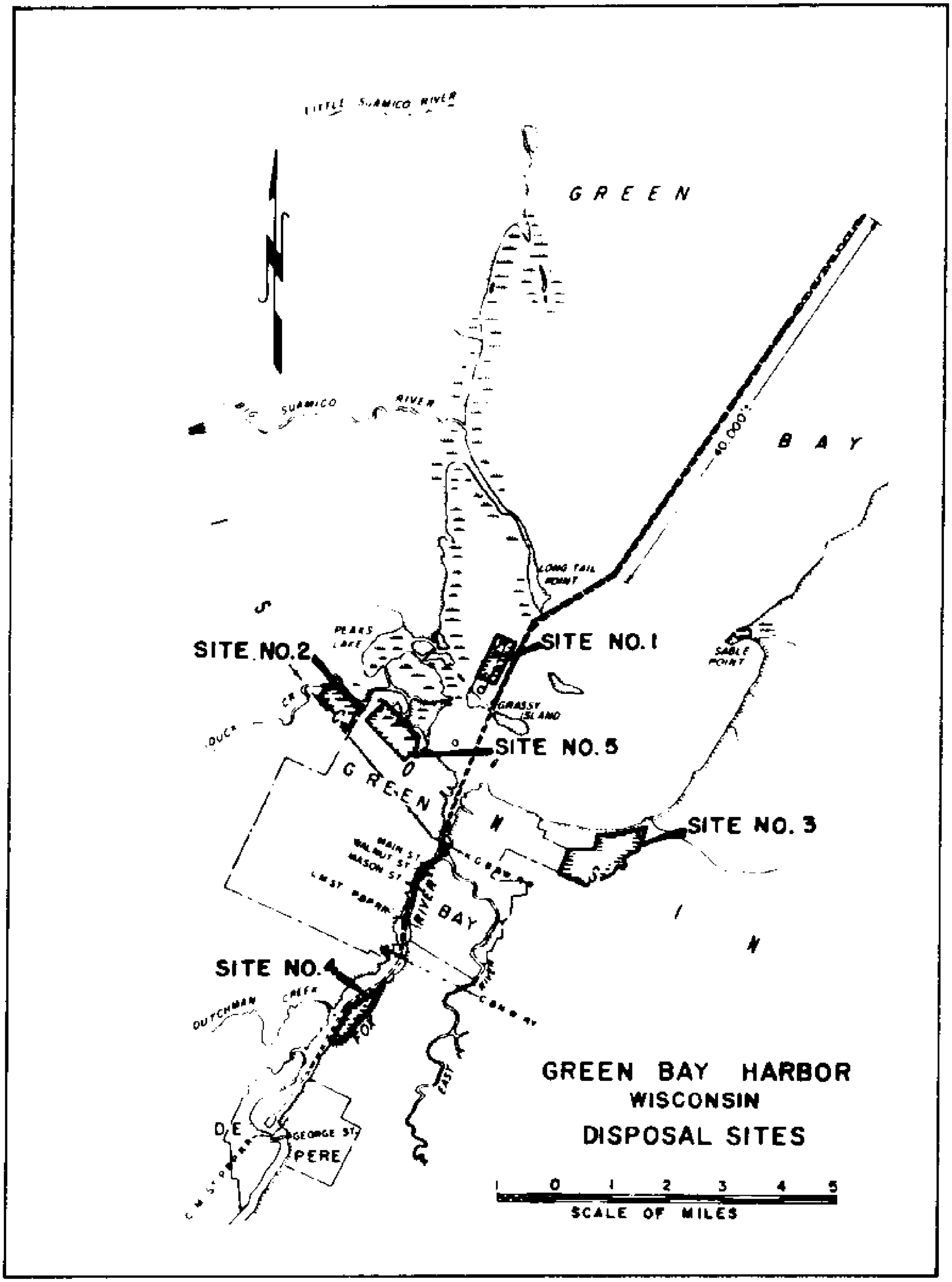


Figure 31. Alternate Spoil Disposal Areas at Green Bay Harbor, Wisconsin. Source: U.S. Army Corps of Engineers, Dredging and Water Quality Problems in the Great Lakes, Summary Report (1969).

Between 750,000 and 1,000,000 cubic yards were added in 1974. The fill area has a remaining capacity of about 250,000 cubic yards which will be filled in 1975 when the harbor is again dredged.

The Corps anticipates annual maintenance will be necessary on the channel until the slopes that were steepened by channel deepening in the late 1960s have stabilized. Spoils that are not polluted are to be deposited in deep water about 15 miles north of Long Tail Point. However, polluted spoils will very possible go to a diked area north of Grassy Island. The Corps had prepared this site before Atkinson Marsh became available to them. Though the dikes have not been maintained and will need repair, the area is still qualified to receive spoils (per. comm., Chicago District Office, U.S. Army Corps of Engineers).

While the Atkinson Marsh dike has been fairly successful in containing spoils, its effects on the immediately adjacent waters are uncertain. The marsh has been filled in such a manner that the excess water from the spoils can drain back into the bay via an outlet pipe or weir. Tests at the outlet pipe by the EPA several years ago suggested that the "settling pond" effect of the dike was effective in reducing turbidity in the effluent water (U.S. Army Corps of Engineers, 1966). However, concentrations of nitrogen, phosphorus, and chemical oxygen demand in the run-off water were higher than levels in either the bay water or the impoundment area (Table 27). In addition, the rapid rate of filling at the marsh in the last two years has reduced the volume of the impounding area and consequently reduced the settling time for suspended material. Thus, for a period of time, more suspended sediment will be returning to the bay via the weir as the filling nears completion.

Table 27.

Water Quality Measurements Inside the Diked Disposal Area and at the Outlet Pipe, Atkinson Marsh, Green Bay

Parameter	Units	Inside Dike at 2 Points	Outlet Pipe
Turbidity	APHA	24-10.0	9.0
Total Phosphorus-P	mg/l	0.59-0.28	0.72
Soluble Phosphorus-P	mg/l	0.18-0.12	0.18
Nitrogen NO_3	mg/l	2.9-2.1	1.9
Nitrogen NH_3	mg/l	5.8-4.7	6.9
Nitrogen, organic	mg/l	4.2-3.6	6.1
Dissolved Solids	mg/l	386-420	406.0
Suspended Solids	mg/l	117-38	92.0
Chemical Oxygen Demand	mg/l	98-78	107.0

From: Dredging and Water Quality Problems in the Great Lakes. Appendix A9, Green Bay Pilot Study, U.S. Army Corps of Engineers, Buffalo District, 1969.

Apparently other solid materials have also made their escape from the dike. Besides channel dredgings, the Atkinson Marsh has received fly ash from the Pulliam Power Plant situated at the mouth of the Fox. In some areas of the fill, fly ash is six feet deep. According to an unpublished Corps report:

> The ash is unprotected from the erosive forces of wind and is airborne by even the lightest breeze... During winter months newly dumped fly ash material is picked up and carried north onto the bay by the wind and alternating layers of snow and ash are created on the ice surface. In the spring, the snow and ice melt and the ash is precipitated into the bay water. Fly ash has also been dumped on portions of the bayshore north of the dike wall and high water and waves have washed the material into the bay. Areas where the ash has been deposited are generally devoid of vegetation and represent a sterile disturbed environment (U.S. Army Corps of Engineers, 1975, p. 10).

While new work dredgings and fly ash may be acceptable fill, maintenance spoils have several undesirable qualities. According to the Corps, these dredgings "consist principally of silts and clays interspersed with varying amounts of organic matter. The resulting mixture has a high water retention capacity and may take many years to consolidate fully" (U.S. Army Corps of Engineers, 1969, p. 7.33).

In two experimental sites in other harbors, tests in 1968 showed that spoils dumped in the early 1960s still held much water and had low shear strengths. The Corps concluded:

> ...fills of this kind, while satisfactory for park land or agricultural use, can be stabilized only at much expense either by cost stabilization, excavation and introduction of suitable foundation materials under loads, or by driving piles into underlying soils (U.S. Army Corps of Engineers, 1969, p. 7.33)

For these reasons, the Corps has had difficulty in finding recipients for their polluted maintenance spoils. Land developers who would gladly take new work dredging are very leery of polluted sediments. And the prevailing attitude among foundation engineers is that most spoil from maintenance operations are deficient in terms of soil mechanics.

> Greatest objections were raised with regard to the projects that involved only light to moderate foundation loads, such as highways and single-story residences. Projects where relatively heavy loads occur such as industrial plants and multistory buildings have been successfully built on spoil in many instances. However, this is because more expensive foundation design (e.g. piles) is necessary and the value of the project is sufficient to make it economically feasible (U.S. Army Corps of Engineers, 1972, p. 103).

Green Bay City has accepted the Corps channel dredgings largely because they contained a major share of new work spoils. Green Bay City is not the only area with a spoils disposal problem. Maintenance dredgings from the inner channel of Sturgeon Bay are also polluted and must be dumped in a contained area. The Corps is presently discussing possible sites with the officials of Sturgeon Bay and Door County (per. comm., Chicago District Office, U.S. Army Corps of Engineers). There has not been any dredging in the channel since 1969 and maintenance work is due soon.

The traffic of large ships brought to Sturgeon Bay by Bay Shipbuilding Company apparently will not necessitate new work dredging since the main channel is fairly deep and has been made deeper by the current high water levels. However, the area in the immediate area of Bay Shipbuilding will be privately dredged (100,000 cubic yards), pending approval of a permit (per. comm., Chicago District Office, U.S. Army Corps of Engineers).

The Marinette Harbor on the Menominee River contains polluted sediments, but there is currently no dredging because a contained disposal site is not yet available. The Corps is now negotiating the possible use of Marinette City land adjacent to the south branch of the Menominee River. This land is about three to four feet above water level (per. comm., Chicago District Office, U.S. Corps of Engineers).

Oconto and Suamico Harbor spoils are "clean" and the occasional dredgings there will be disposed in open water sites. Due to reduced traffic in recent years, future maintenance dredging in Big Suamico will be to depths less than the eight-foot draft originally specified. Peshtigo Harbor, which was not initially designated as a federal navigation way, is not maintained by the Corps (per. comm., Chicago District Office, U.S. Corps of Engineers).

The Pensaukee Harbor has not been dredged since open water disposal was curtailed. Before any further dredging occurs, it is necessary to determine whether Pensaukee spoils are polluted or clean. The Corps is seeking information from the EPA on this matter before seeking a disposal site.

The outer ship channels of both Green Bay and Sturgeon Bay are clean and their spoils are disposed of in open water.

According to the Corps of Engineers, the biggest source of sediments filling up harbors and channels is land erosion, particularly farmland erosion (U. S. Army Corps of Engineers, 1969). Besides the costly side effects of eutrophication wrought by nutrient-rich sediments, there are the direct costs involved in dredging and disposing of these materials — overall a very expensive proposition. When the organic debris of industrial and municipal waste is added to the sediment, disposal of the polluted material becomes even more costly and requires special handling.

While the use of contained disposal sites and on-land disposal sites removes polluted spoils from the aquatic system, the removal may be only temporary unless the site is carefully chosen and prepared. This is particularly true of a contained near-shore site. It is known that toxic materials may reenter the water column when the sediments in which they were buried are disturbed. It is also known that these pollutants may then return to the aquatic system in the water which drains from the spoils. Even when the disposal occurs at an inland site, there is the potential problem of toxic materials leaching from the spoil site into groundwater supplies.

The Corps of Engineers, in its Great Lakes dredge spoil study considered the feasibility of processing polluted spoils in ways that would reduce their toxicity before returning the spoils or their drainage waters back to the aquatic system (U.S. Army Corps of Engineers, 1972). The main problem was to separate the solids from the polluted water of the mud. Several methods suggested were the flocculation of suspended solids by chemical treatment; the use of a hydrocyclone to separate solids from liquids; and dewatering of contained spoils by a vacuum filter. The water removed by these processes was then to be treated in some manner, preferably through an existing sewage treatment facility. In cases where the spoils were highly organic, mechanical aeration of the sediments or multi-hearth incineration were suggested.

The Corps concluded, however, that "since each of these processes can be expected to increase the cost of disposal, treatment should be reserved for the most appropriate cases" (U.S. Army Corps of Engineers, 1972, p. 98).

c. Private Dredge and Fill

Besides the dredging operations of the Corps, there are a number of private dredging activities in the bay each year. Dredging of materials from public and private slips and alongside of docks outside of the federal channel must be done and paid for by the respective owners (Federal Water Pollution Control Administration, 1968). While the "law requires" that a federal permit be secured before any dredge or fill occurs in navigable waters, hundreds of illegal dredges and fills occur on Lake Michigan each year. This problem is now receiving greater attention, partly as the result of a Congressional hearing in 1972 (U.S. Congress, Committee on Government Operations, 1972). According to the Bureau of Sport Fisheries and Wildlife, a major critic of the Corps' position on these matters, there are two types of violators,

> — the fellow who wants to install small facilities and out of ignorance just doesn't apply for a permit, and the professional developer who intentionally or otherwise does not apply for a permit but carries out his project hoping he doesn't get caught, knowing full well that if he does it will probably mean only a delay in his work (U.S. Congress Committee on Government Operations, 1972, p. 21).

In the Green Bay area, the nature of illegal activities varies with water levels. At low water, dredging is the problem while during high water it is unauthorized fills. The Office of the Fish and Wildlife Service in Green Bay is now cooperating in an aerial surveillance program with the Corps. This will consist of regular flights over the bay shoreline. Where illegal construction is seen, ground evidence will be collected and the case will be turned over to the district attorney (per. comm., Richard Hoppe, Bureau of Sport Fisheries and Wildlife). This program, however, has been complicated by the fluctuating water levels of the last decade. This has made it very difficult to establish a baseline point for "normal" water level with which to compare present levels. As a result, aerial surveillance can only be effective where fill activities are blatantly visible.

d. Environmental Effects

Although the environmental impacts of dredging and open water disposal are generally fairly localized, circulatory currents can disperse fine sediments or resuspended toxic materials over a wide area.

New work dredgings are the most physically disrupting dredge activities since they remove large amounts of previously undisturbed sediment and/or bedrock. The gross effects, however, are restricted to the immediate area and actually may be less damaging to the biological system than the open water disposal of polluted spoils.

Maintenance dredgings are less disruptive because the harbor or channel areas usually contain "light shifting substrate which are not conducive to extensive benthic growth." In other words, after the initial dredging, maintenance channels are seldom well-resettled by animals.

However, there are indirect effects of dredging which can be far-reaching.

> These...include changes in the bottom geometry and the creation of deep-water regions, new open water, changes in bottom substrates and habitats, alterations in water velocity and current patterns, changes in future sediment distribution patterns, alteration of sediment-water interface with subsequent release of biostimulatory or toxic chemicals, and the creation of turbidity clouds (U.S. Army Corps of Engineers, 1972, p. 40)

The effects associated with disposal of spoils are somewhat similar and include sediment build-up, oxygen depletion and turbidity.

Sediment build-up destroys fish spawning beds and buries fish eggs. It also smothers benthic animals and rooted vegetation and generally reduces habitat diversity. Rapid sedimentation can carry organic materials with high BOD into the bottom muds where they deplete oxygen and release noxious compounds (U.S. Army Corps of Engineers, 1972).

Whether normal biotic communities are able to reestablish themselves on spoils sites depends largely on the stability of the spoils and their levels of pollutants. Where the spoil is "clean" or new work dredgings, organisms may become established fairly rapidly. Carriker (1967) concluded that the constant modification of the substrate by tube building animals would stabilize the sediments and pave the way for a succession of species. But he also pointed out that the success of individual species in recolonizing a spoil site is dependent on the larval phase finding a suitable substrate on which to develop.

Recolonization of spoils can often be facilitated by assuring that the spoil and disposal site have similar sediments in common: that sand is dumped on sand, and mud on mud (U.S. Army Corps of Engineers, 1972).

Perhaps the most damaging result of dredging — beyond the gross destruction of habitat — is the increase in water turbidity. Turbidity is caused by the suspension of very fine particles, both organic and inorganic in the water column. It is not only aesthetically displeasing, but also reduces light penetration (Ellis, 1936). The diminution of light, in turn, reduces the depth of the euphotic zone and thereby limits basic productivity (Bartsch, 1960). (Conversely, the release of nutrients from disturbed sediments may have the overall effect of stimulating plant productivity [Copeland and Dickens, 1969].) As suspended materials flocculate, they can mechanically trap phytoplankton and drag them to the bottom. Fish, while they may continue living in turbid water, show reduced growth in waters with more than 25 ppm suspended solids (Buck, 1956; EIFAC, 1964). Turbidity can also influence water temperatures and the mixing of water layers (Bartsch, 1960; Cairns, 1968).

In the lower half of Green Bay, turbidity is a constant problem. To what degree it is man-caused is unclear. It is also unclear what effect a reduction in any man-made sources would have on the bay. As the Corps pointed out, "... materials discharged in waters that are normally turbid would produce almost negligible effect (on the ecosystem)" (U.S. Army Corps of Engineers, 1972).

The most obvious natural force producing high turbidity is the wind which constantly stirs the shallows from spring to fall and resuspends fine materials. Marshes have the capacity to temper much of this turbidity by filtering and sifting suspended solids. Though marshes still function in this way on Green Bay, their importance as sediment filters now — and in the past when they were considerably more extensive — is not known.

Yet bits of evidence suggest that turbidity today is greater than in the past and that at least a portion of it is unnatural:

> At one time extensive wild celery beds grew within Dead Horse Bay, but these have been greatly reduced due to turbidity, caused by a cumulation of factors, including carp activity, water-pollution, channel dredging and open water disposal of dredge material (U.S. Army Corps of Engineers, 1975a, p. 18)

Shipping also, even though confined to the narrow stretch of a ship channel, can have a disturbing effect. In fact, the Corps equates the turbulence created by the passage of a large vessel with that caused by dredging. While these effects may be "temporary," they are often repeated, occasionally several times in one day during the shipping season. However, this turbulence is generally restricted to the shipping channels which are relatively devoid of life.

According to Brehmer (1965) the estuarine zone of the oceans, which bears many similarities to Green Bay, is both a highly productive area and the zone with highest levels of suspended soils. Brehmer suggests that the turbidity in this zone may be a factor in seasonal fluctuation of fish species. If a natural relationship between periods of turbidity and fluctuations of fish populations exists in Green Bay, one must question whether it has been altered by the presently high turbidity levels.

Tied to this question, of course, is the role of carp in the bay. The carp are known to uproot and damage submergent macrophytes which act as important sediment filtering mechanisms. The contribution of carp to turbidity in the lower bay deserves consideration (see discussion on pp. 152, 162).

5. EROSION AND FLOODING

5.1 FLUCTUATING WATER LEVELS

a. Problems on Lake Michigan

Since man began to officially measure the water levels of Lake Michigan in the 1860s, the levels have risen and fallen several times. The low water datum is 576.8 feet above mean sea level as measured at Father Point, Quebec. Low water datum is the plane on the lake to which the Lake Survey chart depths and the federal navigation improvement depths are referred. Except for a period in the 1930s and another period between 1962 and 1966, water level has remained above this datum point. The highest recorded level was 4.5 feet above low water datum (1884-1886). In 1974, the water level rose to 3.2 feet above the datum, the highest water on the lake since 1952 (Figure 32). These present high levels are considered by some meteorologists to be the reflection of a world-wide climatic change that is bringing increased precipitation to the Great Lakes region (Bryson, 1973, 1974; Alexander 1974). If these predictions are correct, Lake Michigan water levels may rise and fall from year to year but will show a general trend toward higher levels than those experienced over the last 40 years.

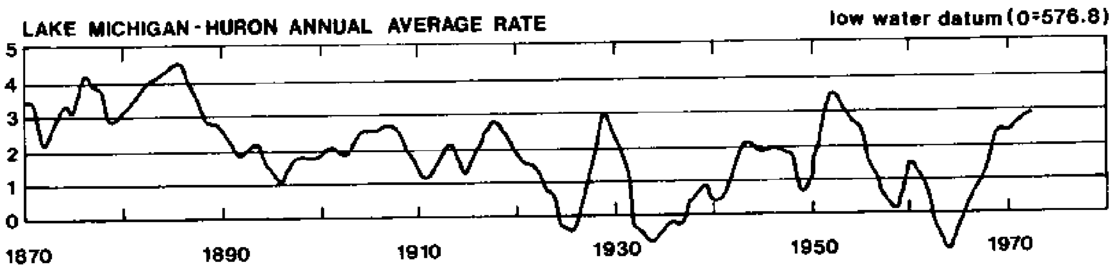


Figure 32. Water level fluctuations on Lake Michigan, 1870-1973. From Sea Grant Advisory Services pamphlet "Shore Erosion on the Coast of Lake Michigan."

Fluctuating water levels would be no more than a hydrologic curiosity if it were not for the fact that very high or very low levels cause extensive property damage and loss of revenue. Extreme low water exposes normally submerged structures and accelerates their decay. It can leave moorings and marinas high and dry and unusable—unless expensive dredging or filling is done. Low water can decrease the draft in commercial harbors and reduce the loading capacity of ships (International Great Lakes Levels Board, 1973).

High water can also render small harbors unusable by inundating docks and launching ramps, and decreasing marina area. High water, however, is generally beneficial to navigation since it increases harbor draft and improves access to wharves. Major private and federal harbor facilities also fare better in general because they are designed to withstand the known range of water levels (International Great Lakes Levels Board, 1973).

The shores of Green Bay, like the rest of Lake Michigan's shoreline, have suffered millions of dollars worth of damage from storms which have occurred during the current high levels. The reason is the geology of the lakeshore itself. With the exception of occasional areas of exposed bedrock, such as found on the Door County shore, most of Lake Michigan's coast consists of unconsolidated and erodable sediments left by the retreating continental glacier. In some areas the shore is composed of steep banks of glacial tills and red clays. In other places, for example the western shore of Green Bay, the coast is low-lying and made up of the sands and silts left by a shrinking glacial lake (Harris, Yarbrough and Pezzetta, 1974). Over the last few years the rising waters of Lake Michigan have eroded beaches and cut into the base of the unconsolidated bluffs and dunes, causing them to slump. In the Green Bay region the extensive lowland areas have been inundated.

b. Damage from High Water

Estimates of damage caused by high water are difficult to assess accurately because much of the loss goes unreported. The Corps of Engineers, however, did assess flooding and erosion damages of the 1954 high water period along Green Bay shores (Table 28). Using a multiplier factor that takes into account inflated property values and the increased residential and commercial development along the shore area since 1952, the Corps calculated the cost of similar high water levels in 1970 (U.S. Army Corps of Engineers, 1971). Recent water levels while only slightly higher than those of 1952 have caused considerably more damage and affected more property owners than in the past. The shore of Menominee County, Michigan for example, had an increase in residential development of 33 percent and an increase in recreation property of 140 percent since 1952 (U.S. Army Corps of Engineers, 1971). In addition, the last twenty years has seen an increase in the number of man-made jetties and other structures extending out from the shore. These structures have accelerated erosion in some areas by altering the flow of sand along the shore, leaving some bluffs without beaches or sand bars to protect them from waves.

Detailed assessments of more recent high water damage in the Green Bay area have focused on Brown County and particularly on the cost of the storm of April 9-10, 1973. The flooding of southern Green Bay which accompanied the storm was evaluated by U.S. Geologic Survey which took water level measurements along the shore at the city of Green Bay (per. comm., William Rose, USGS). Measurements were also made from one mile north of Duck Creek on the west shore, and one mile north of Point Sable on the east shore, to the Green Bay city limits. Besides delineating the flooded areas, the USGS ran a frequency analysis to determine the severity of the storm. The USGS calculated that 6.2 square miles of Brown County shore and river frontage were inundated. The greatest portion, 59 percent, was undeveloped agricultural land. The remainder was 16 percent residential, 15 percent recreational and 10 percent commercial or industrial.

Table 28. Shoreline Damage From 1972 High Water Levels in Green Bay

Area	Actual Cost / Est. Cost	PRIVATE OWNERSHIP Resi-dential	Industrial and Com-mercial	Agri-culture	Total Private	PUBLIC OWNERSHIP Parks and Beaches	Harbor Instal-lation	Utili-ties	Total Public	Total Cost of Damage
Menominee County, Michigan	1952	$44,000	$3,000	--	$47,000	$ 2,400	$ 10,000	--	$ 12,400	$59,400
	1970	85,000	5,800	--	90,800	5,500	19,300	--	24,800	115,600
East Limit of Green Bay City to Tip of Door County	1952	$84,500	$73,300	$25,000	$182,800	$13,200	--	--	$13,200	$196,000
	1970	163,100	141,500	26,200	330,800	30,500	--	--	30,500	361,300
East Limit of Green Bay City to North Limit of Marinette Co.	1952	$39,000	$42,000	$16,000	$97,000	$9,000	--	$ 62,000	$71,000	$168,000
	1970	75,300	81,100	16,800	173,200	20,800	--	143,200	164,000	337,200
Delta, School-craft & Mackinac Counties, Mich*	1952	$8,000**	$73,000	$8,000	$89,000	$3,000	$5,000	$284,000	$292,000	$381,000
	1970	15,440	140,890	8,400	164,730	6,930	11,550	656,040	674,520	839,250
TOTAL	1952				$415,800				$388,600	$804,400
	1970				759,530				893,820	1,653,350

* Does not include coast of Delta County from Gladstone to Menominee County line.

**Commereial only

The bulk of the storm's damage occurred in Green Bay city east of the Fox River where there was severe erosion as well as flooding. At least one mile of this shore frontage is primarily residential. Damage reported from flooding and erosion in Green Bay city is shown in Table 29. Note the large discrepancy between the estimated cost of damage and the amount actually reported to Green Bay Department of Public Works. Some observers feel the real damage to residential property may have been even higher than the 2.9 million dollars estimated.

Table 29. Property Damage in the City of Green Bay from April 9-10, 1973 Storm

Category of Property	Reported Cases of Damage	% of Damaged Properties Reporting	Cost for Reported Properties	Estimated Cost for all Properties
Residential	209	23%	$ 683,793	$2,973,000
Commercial	43 (Commercial and Industrial)	100% (Commercial and Industrial)	645,000	645,000
Industrial			410,000	410,000
Public Lands	--	--	160,000	160,000
TOTAL			$2,393,793	$4,188,000

A survey of property damage in Brown County, funded by the Corps of Engineers and administered by the Wisconsin DNR and UW-Milwaukee Center for Great Lakes Studies, is currently underway. The survey consists of a questionnaire to 15 percent of all residential shoreline property owners and 100 percent of commercial and industrial property owners in the high water areas. It asks for information on assessed valuation of property and the amount of damage sustained (per. comm. John Pezzetta, UW-Green Bay).

The kind of property damage occurring along Green Bay's shores varies with the shoreline character and the type of structure involved (Table 30 and Figure 33). The Corps report of 1971 states that shoreline flooding occurs in the city of Green Bay when the water level rises 4.5 feet above low water datum (U.S. Army Corps of Engineers, 1971). On the west bayshore, from Duck Creek to Peshtigo, the low sandy shorelands flood when the lake rises only 2.5 feet above low water datum. Low bluffs and dunes in the area between Peshtigo and Marinette are more subject to slight erosion than to flooding. North of Marinette County, the Michigan coastline consists of low plain which is subject to erosion damage when lake levels are high and the waters are driven by strong northeast winds. During the 1952 high water period, the Menominee County shore eroded an average 10 feet. However, as of 1970, shore erosion and damage was minimal in the area. Some flooding also occurs along the banks of the Menominee River when bay levels

TABLE 30A
EROSION AND FLOODING IN MARINETTE, OCONTO, AND BROWN COUNTIES, WISCONSIN

Shoreland Use Category	*Problem Identification, Miles of Shoreline*				
	Subject to Erosion		*Protected*	*Subject to Flooding*	*Not Subject to Erosion or Flooding*
	*Critical**	*Noncritical*			
Economic Uses					
Residential	0	7.5	1.9	16.5	0
Industrial and commercial	0	0	0	1.1	0
Agricultural and undeveloped	0	4.3	0	22.5	0
Commercial harbors					
Electric power sites					
Public buildings and related lands	0	0	0	0	0
Recreational Uses					
Parks	0	0.4	0	0.7	0
Recreational boat harbors					
Beach zone					
Environmental Uses					
Wildlife perserves and game lands	0	0	0	17.2	0
Fish and wildlife wetlands (offshore)					
Forest	0	0	0	3.9	0
Total	0	12.2	1.9	61.9	0

*The Corps of Engineers defines critical erosion as that which causes sufficient economic and property loss to justify protective measures.

TABLE 30B
EROSION AND FLOODING IN MENOMINEE COUNTY, MICHIGAN

Shoreland Use Category	*Problem Identification, Miles of Shoreline*				
	Subject to Erosion		*Protected*	*Subject to Flooding*	*Not Subject to Erosion or Flooding*
	Critical	*Noncritical*			
Economic Uses					
Residential	0	17.4	0	0	0
Industrial and commercial	0	2.9	0	0	0
Agricultural and undeveloped	0	1.5	0	0	0
Commercial harbors					
Electric power sites					
Buildings and related lands	0	0.1	0	0	0
Recreational Uses					
Parks	0	5.0	0	0	0
Recreational boat harbors					
Beach zone					
Environmental Uses					
Wildlife perserves and game lands	0	0	0	0	0
Fish and wildlife wetlands (offshore)		NA			
Forest	0	12.1	0	0	0
Total	0	39.0	0	0	0

From U.S. Army Corps of Engineers, Great Lakes Region Inventory Report, National Shoreline Study, 1971.

TABLE 30C

DELTA COUNTY TO STRAITS OF MACKINAC BRIDGE, MICHIGAN

Shoreland Use Category	Problem Identification, Miles of Shoreline				
	Subject to Erosion		Protected	Subject to Flooding	Not Subject to Erosion or Flooding
	Critical	Noncritical			
Economic Uses					
Residential	0	12.2	11.7	24.1	9.5
Industrial and commercial	0	2.1	0.6	4.7	0.8
Agricultural and undeveloped	0	3.8	8.2	7.1	24.1
Commercial harbors					
Electric power sites					
Public buildings and related lands	0	0	0	0	0
Recreational Uses					
Parks	0	0.7	1.6	1.0	3.4
Recreational boat harbors					
Beach zone					
Environmental Uses					
Wildlife perserves and game lands	0	0	0	0	0
Fish and wildlife wetlands (offshore)	0	0	0	0	0
Forest	0	17.2	18.5	41.9	94.8
Total	0	36.0	40.6	78.8	132.6

TABLE 30D

EAST CITY LIMIT OF GREEN BAY TO NORTH END OF DOOR COUNTY, WISCONSIN

Shoreland Use Category	Problem Identification, Miles of Shoreline				
	Subject to Erosion		Protected	Subject to Flooding	Not Subject to Erosion or Flooding
	Critical	Noncritical			
Economic Uses					
Residential	0	0	12.2	0	36.6
Industrial and commercial	0	0	0	0	0
Agricultural and undeveloped	0	0	0	0	10.8
Commercial harbors					
Electric power sites					
Public buildings and related lands	0	0	0	0	0.9
Recreational Uses					
Parks	0	0	0	0	9.5
Recreational boat harbors					
Beach zone					
Environmental Uses					
Wildlife perserves and game lands	0	0	0	0	1.0
Fish and wildlife wetlands (offshore)					
Forest	0	0	0	0	22.0
Total	0	0	12.2	0	80.8

From U.S. Army Corps of Engineers, Great Lakes Region Inventory Report, National Shoreline Study, 1971.

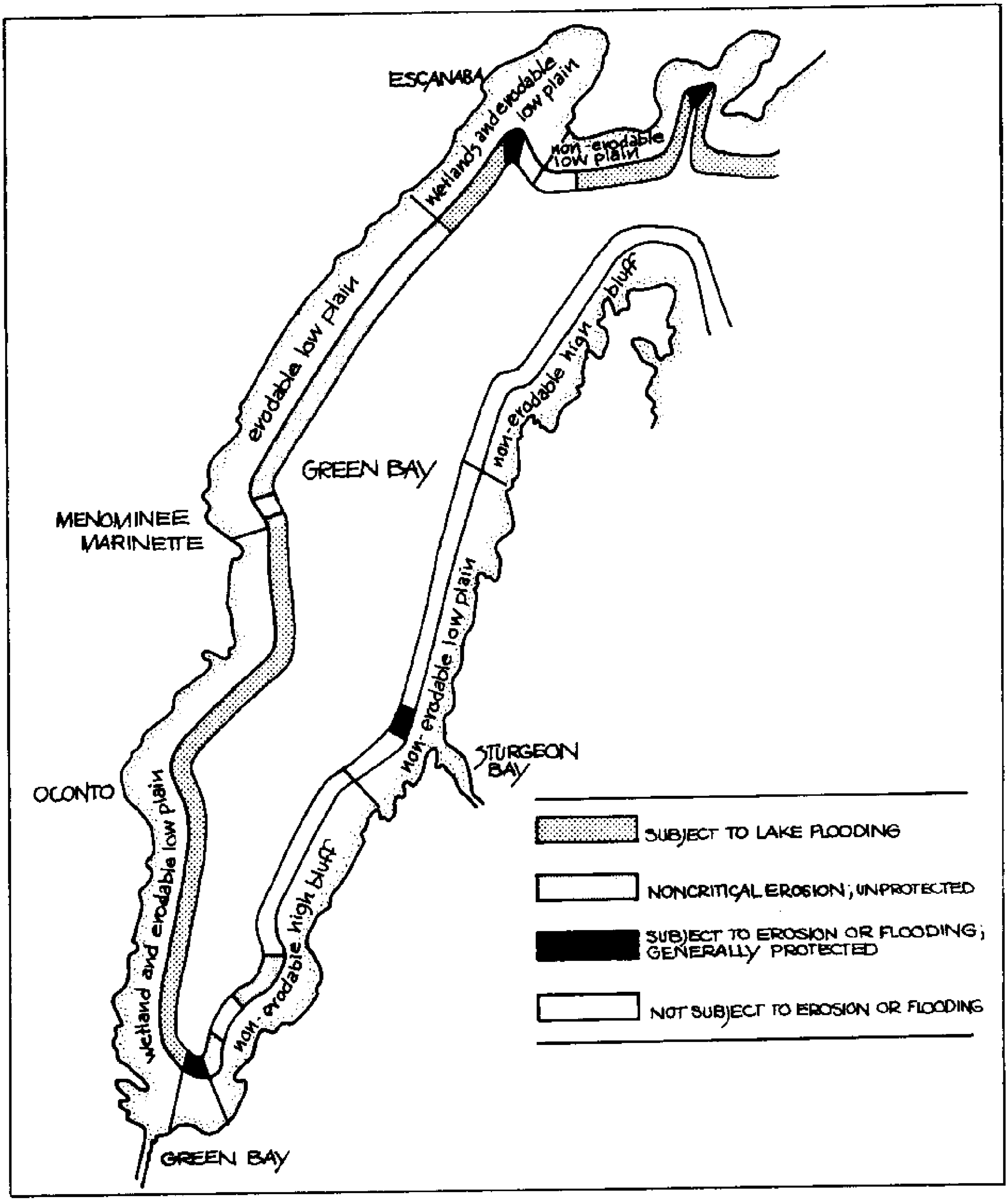


Figure 33. Shoreline Areas Subject to Flooding and Erosion From U.S. Army Corps of Engineers, Great Lakes Region Inventory Report, National Shoreline Study, 1971.

exceed 3 feet above low water datum. The area between the Menominee County line and the city of Gladstone in Delta County consists of low sand banks. Although damage figures are unavailable, the shore eroded an average 10 feet during the 1952 high water period.

Approximately 74 miles of the northern shore of Big and Little Bay de Noc are subject to flooding. But because this coast is mostly undeveloped forest area, there has been no property damage (U.S. Army Corps of Engineers, 1971). Most of this area is free of critical erosion problems. (The Corps of Engineers defines erosion as "critical" when it causes sufficient economic and property loss to justify protective measures. Thus uninhabited shores, though they may be heavily eroded, generally are not "critical" areas.) Much of Delta County is naturally protected by gravel or cobble beaches, and the bays and inlets are generally protected by rock outcroppings.

The east shore of Green Bay is relatively unaffected by high water levels, consisting of either rocky bluffs or protected bays. Much of the damage which has occurred has been due to ice which reached higher on to the shore than during past low water periods (U.S. Army Corps of Engineers, 1971).

c. Effects of Water Levels on Wetlands

As explained in the discussion of the littoral zone (pp. 78-80), fluctuating water levels are an integral part of the wetlands ecology. Harris and Marshall (1963) have stated:

> ...It seems probable that some species of aquatic plants which are regarded as desirable in marshes have developed adaptations for survival in response to these natural fluctuations, even to the point where these plants may actually require such fluctuations for continued survival and seed production.

Both low and high water stages, however, have some deleterious effects. Shoals such as those found off the west shore of Green Bay can be exposed by low water with a consequent reduction in their production of commercial fish and other aquatic life (International Great Lakes Levels Board, 1973a). High water, on the other hand, generally increases fish production by enlarging the area of spawning feeding grounds. However, the same high levels may be harmful to waterfowl populations as wave activity reaches into the marsh and swamps nesting areas.

These natural gains and losses balance out over the years as plant and animal populations are suppressed and then recover. The wetland losses due to man's interference are more permanent, and in terms of gains, there are none to speak of. Most of the man-caused losses are associated with extreme high or low water levels:

> Destruction of shoreline marshes increases during periods of lower lake levels. At such times, the dry marshes are more easily accessible and are used for solid waste dumping. The

present earth moving equipment can destroy a marsh in a relatively short time. Records of permits issued in the last ten years indicate marsh destruction occurring at a rate of several hundred acres annually. These figures are minimal since marshlands adjacent to, but not abutting on the shoreline, can be filled or destroyed without a permit. It is anticipated that, should this type of marsh despoilation continue, 10,000 acres or more will be lost during the next 50 years (International Great Lakes Levels Board, 1973a, p D-96).

In addition, private dredging to facilitate access to docks and marinas during low water periods generally occurs in less than thirty feet of water, a critical environmental zone for plant and animal life (International Great Lakes Levels Board, 1973a).

High water periods also have serious effects on wetlands adjacent to urbanized areas. As the shallow waters move shoreward and cover lawns and roads, landowners respond by adding fill soil, rock slabs and rip-rapping. As the land is brought above water level, the shoreward areas that would normally be recolonized by emergent aquatic vegetation are diminished and the wetlands area itself shrinks.

Part of the difficulty of managing these flood-prone areas and protecting them stems from a general resistance by the local population to any restrictive zoning at the county level or regional planning on the state level. The aquatic "tension zone" is frequently a political tension zone also. Until differences are resolved in the political arena, the wetlands areas will continue to be casualties of the struggle over the right to build on marginal land.

d. Lake Levels and Shoreline Development

The year 1963 was dry, and 1964 was only a slight improvement. In Michigan, inland lakes were the lowest since 1936, considered a drought year.... In the whole Great Lakes area the 3-year rainfall deficit reached 25 inches.... The dread word "drought," with its reminder of the Dust Bowl and of receding, desiccated beaches in Michigan during the thirties, caused many a community to look again to its water resources.

Industrial Uses of Water in Michigan
C. W. Wixom & K. F. Zeisler, 1966

The number of instances noted during the course of field investigation (1971-1973), where people have placed large investments on shore lands actually unsuitable for development due to rapid erosion or inundation at high lake levels, was surprisingly large. *The other surprising thing was that in most cases the information on the land's susceptibility to flooding and wave action was available within living memory of local population.* (Italics ours)

Regulation of Great Lakes Water Levels, Appendix C, Shore Property, Report to the International Joint Commission, 1973. p.c-102

Fluctuating water levels have been a part of life on Green Bay and each period of high or low water has brought grief to the property owner who has forgotten or ignored the fact that the water does not stay put. The time of low water which followed the 1952 "flood" persisted until the late 1960s. During this period the Green Bay region as a whole experienced an increase in both population (Table 50) and affluence. The proliferation of automobiles and the improvement of highways made it possible for more people to have a bay shore cabin or to live year around on the bay and commute to work. During the long years of low water, the temptation to build at the edge of the shore bluffs or down at the water level was great. There was little or no zoning that prohibited building in these relatively unstable areas. Since then the waters have risen and many west shore properties have been totally inundated. Water that had been out of sight beyond the weeds is now on the lawns, if not in the homes, of many bayside dwellers. Yet there has been no mass exodus out of the area. Although there is very little subdivision going on, buildings of value are being elevated or otherwise altered to protect them from further flooding (per. comm., Frank Jobelius, Green Bay realtor). The situation is much like that in a typical river bottom town where poorer quality housing suffers the most damage. Since it is unprofitable to invest in protecting low value property, its quality continues to decline. Better quality structures are able to weather the flood and the owners are willing to make the extra investments to protect them.

The problem of flooded property becomes more serious as more people build expensive permanent structures in flood prone areas and demand protection from flood loss. Recent efforts to discourage development in these wet areas, such as state regulations on septic systems, have not curbed growth. While the installation of a mound septic system or holding tank system is four to five times as expensive as a normal system, this does not seem to be a major deterrent (per. comm., Leland Green, UW-Extension).

One potential solution is a new HUD flood insurance program. The National Flood Insurance Association currently offers inexpensive flood insurance to residents of flood prone areas. But for a homeowner to receive coverage, both he and his local government must quality for the program. This means a town must develop floodplain zoning regulations and apply to the U.S. Department of Housing and Urban Development. According to the Wisconsin DNR, Brown County has adopted the necessary zoning and applied for coverage by the flood insurance program. However, neither Oconto nor Marinette Counties have followed suit (per. comm., Wisconsin DNR). After July 1, 1975, loans to buy homes in flood-prone areas will be practically unavailable and federal flood relief will also be restricted.

Unfortunately, there is relatively little that can be done to lower the levels of Green Bay or Lake Michigan. More water can be released through the Chicago River but its overall impact is to reduce levels by two to three inches at the most over a year's time. A second alternative is to retain more water in Lake Superior, letting the levels rise higher on that less populated lake. It is roughly estimated that such a holdback over a period of a few years could lower Lake Michigan levels by a foot or more. An emergency holdback of water in Lake Superior between February 1973 and 1974 lowered Lake Michigan by about 5 inches and raised Lake Superior by about 8 inches (Committee on Public Works, House of Representatives, 1973). It is expected that even with a holdback changes in water levels on the two lakes will vary. This variance will depend on the climate and on the requirements of power utilities and other interests for a minimum flow out of Lake Superior. Because of such institutional factors, water probably would be held back only 30 percent to 40 percent of the time (per. comm., James Knox, UW-Madison). The costs and benefits of such a decision are currently being considered by the International Joint Commission and the respective states and provinces which border Lake Superior (International Great Lakes Levels Board, 1973).

A third, less likely alternative proposed by some, is to pull back development from the lakeshore and allow nature to take its course. Less extreme variations on this idea, however, mentioned above, are being employed to discourage future development in areas prone to erosion or flooding.

While it is expected that the Corps of Engineers will utlimately hold back water in Lake Superior, the problems of flooding and erosion will be only temporarily modified by this step rather than solved.

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PART II

Cultural, Economic and Historical Characteristics of the Green Bay Region

6. FISHERIES

6.1 EARLY HISTORY

Rugged immigrants from Iceland and Norway had built their shoreside cabins and begun fishing the remote waters of Green Bay long before the region had attracted the attention of other settlers. The fishermen, like the lumberjacks who came later, were a special breed. Their year revolved around the cycles of the bay: the spawning and feeding movements of fish, and the coming and going of the winter ice.

The most intensively sought species in the early fishery were the whitefish and lake herring. These fish were salted and packed off to eastern and midwestern markets where they were in great demand. Besides these, there were also wall-eye and northern pike, lake trout, and deepwater ciscoes.

What the fishermen caught and how they caught it depended largely on the area of the bay and the time of year in which they were fishing. Some idea of the diversity of fish habitat within the bay can be gotten from Charles Lloyd's description of the bay.[1] Lloyd divided the water of Green Bay into five regions, each with characteristic limnological features. These regions, shown in Figure 34 are described as follows:

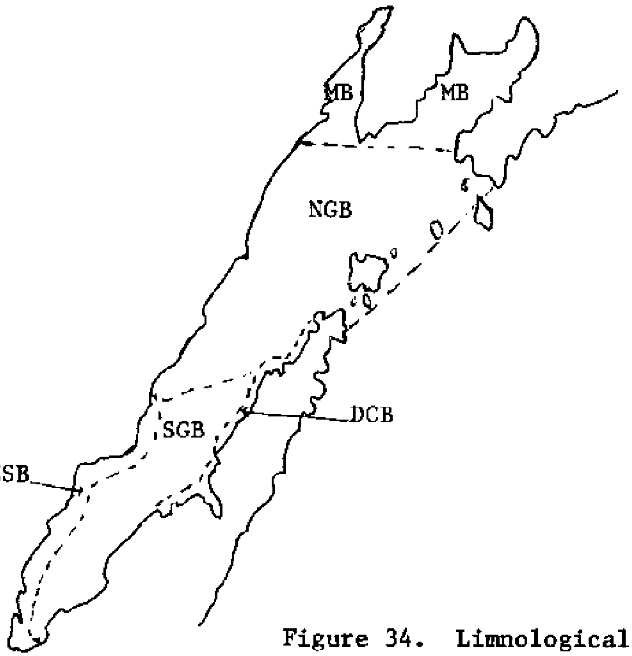
1. Northern Green Bay (NGB) - the main body of water north of a line from Marinette to Door County. About 85 percent of the area is under more than 30 feet of water and maximum depths of 160 feet occur. A thermocline forms at a depth of 40 feet, providing a deep cold-water habitat. This portion of the bay receives flows from the relatively small Escanaba and Whitefish River watersheds and is subject to some influence by Lake Michigan waters.

2. The Michigan Bays (MB) - Little and Big Bay de Noc on Michigan's Upper Peninsula. These are large open bays of moderate depths and are suitable to both warm water fish and some colder water fish.

3. Southern Green Bay (SGB) - that portion of the bay south of a line from Marinette, through Chambers Island to Door County. This region receives drainage from one major river, the Fox, as well as from the Menominee, Oconto, Peshtigo, Pensaukee and Suamico Rivers. Half of the bay's area here is less than 30 feet deep, making an essentially eutrophic warm-water habitat. The waters are generally well-mixed.

4. Estuaries and Sandbars (ESB) - those areas on the west shore and south end of Green Bay which comprise the weedy shallow waters in which no thermocline forms. These are warm water habitats and occur primarily at the delta fans of rivers and behind sandbars like Long Tail Point. Most of this habitat is on the shore of Oconto, Brown and Marinette counties in Wisconsin.

5. The Door County Bays (DCB) - Ellison Bay, Sister Bay, Eagle Harbor, Fish Creek, Egg Harbor, Sturgeon Bay and Little Sturgeon Bay. These bays have relatively warm shallow waters and behave much like inland lakes.

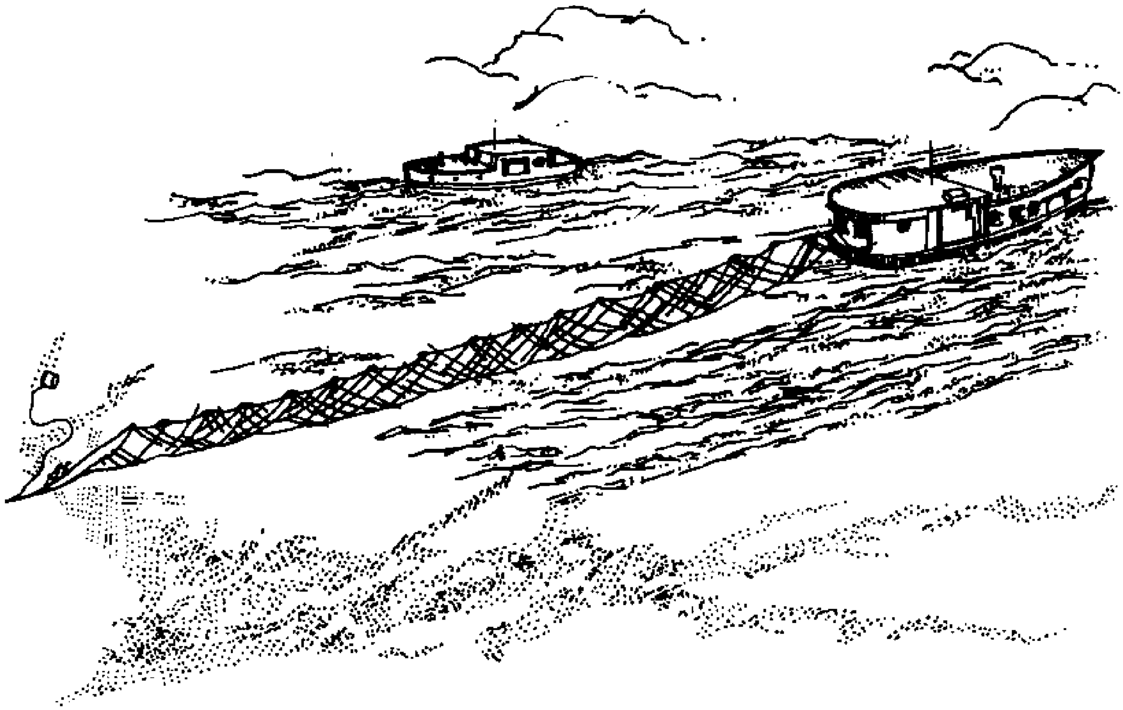


SGB - Southern Green Bay
NGB - Northern Green Bay
MB - Michigan Bays
DCB - Door County Bays
ESB - Estuaries and Sand Bars

Figure 34. Limnological Regions of Green Bay According to Charles Lloyd. From: Proceedings of Governor's Conference on Lake Michigan Pollution (1966).

Combining Lloyd's regions with the 1887 reports of the U.S. Fish Commission,[2] the location and characteristics of past fisheries of Green Bay can be summarized as follows:

The northern fisheries were mainly deep water gill net operations (Figure 35) that took lake trout and whitefish. Fishing was centered around the islands at the mouth of the bay where several distinct fishing grounds occurred. Shown as approximate locations in Figure 36, these were known as the Sack Bay, Summer Island, St. Martin Island and Washington Island grounds, respectively. During the peak of the island fishery, in the 1840's and 1850's, approximately 20 fishing families lived year-around on Summer Island and several more lived on Rock Island. However, with the decline in whitefish catch and the advent of the steam tug in 1869, most of the fisherman left the smaller islands. (The steam tug, a more versatile vessel than the traditional fishing sloop, enabled fisherman to live farther from the fishing grounds and venture farther from shore.) By 1885 only four families remained on the islands, most of the fisherman then making their headquarters at the harbors of Big and Little Bay de Noc. While Washington Island continued to support fishing families, the number of gill net crews dropped from 25 in the 1870's to 8 in 1885.



"Some commercial fishing in the Great Lakes region is carried on by gill net tugs of 30 to 50 feet in length and built to stand severe winter weather on the Lakes. The boats' cruising range is limited and they return to their ports every day. The gill net tugs keep from 4 to 7 gangs of nets in the Lake at all times, each gang consisting of appwroximately 10 separate boxes of nets with each box containing approximately 200 fathoms of netting. These nets are stored in metal or wooden boxes of that capacity."

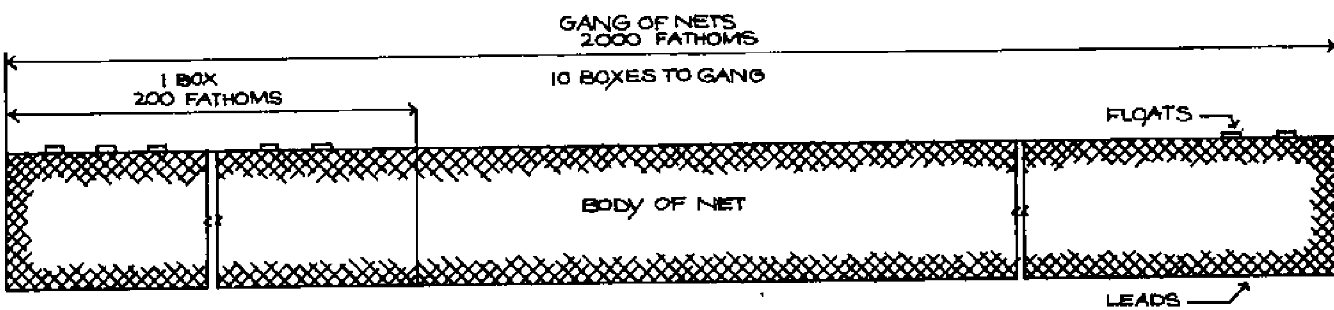


Figure 35 - Contemporary Great Lakes Gill Netting Apparatus. From Nets, The Commercial Fisherman's Reference Book, R.J. Ederer Co., Chicago, 1948.

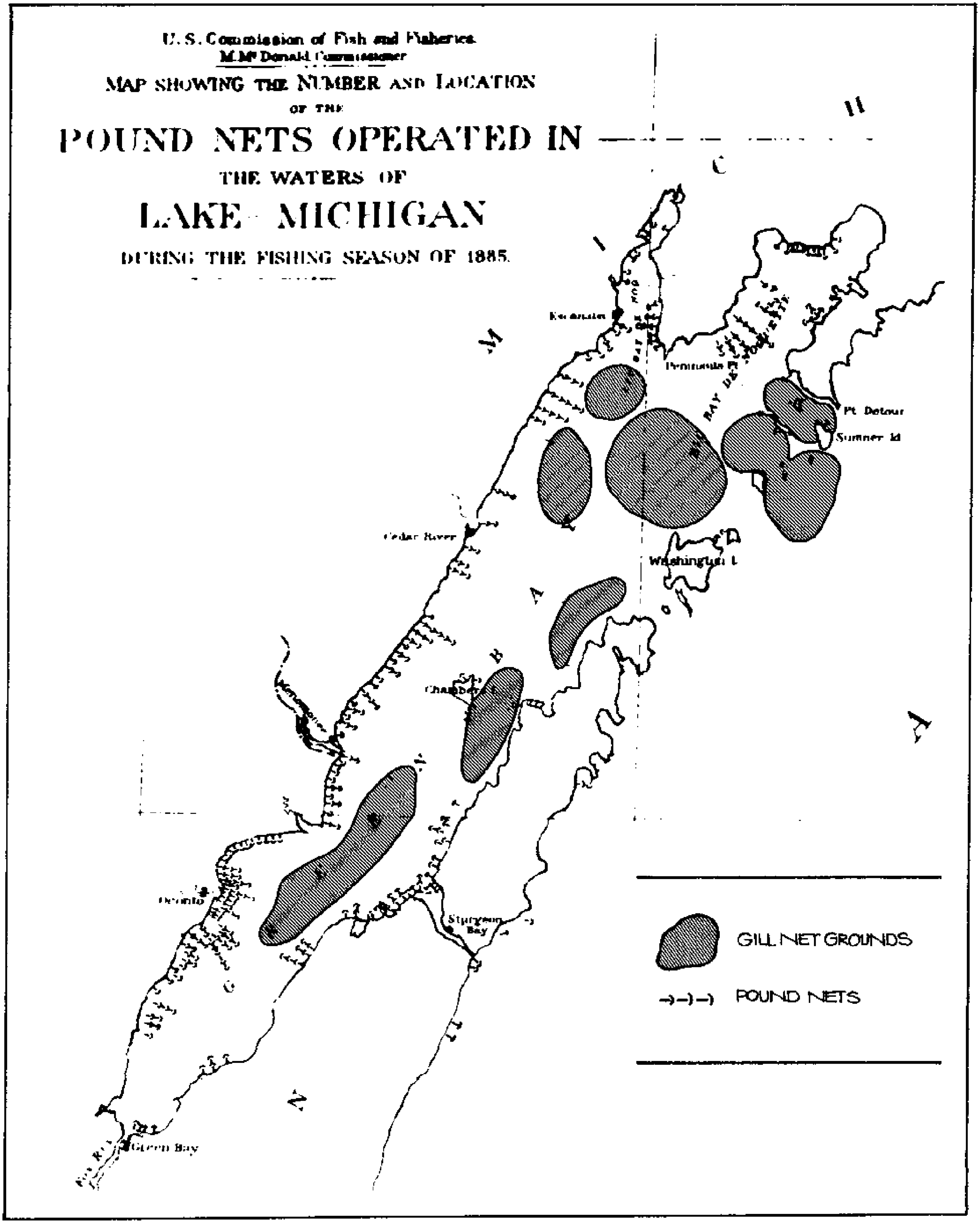
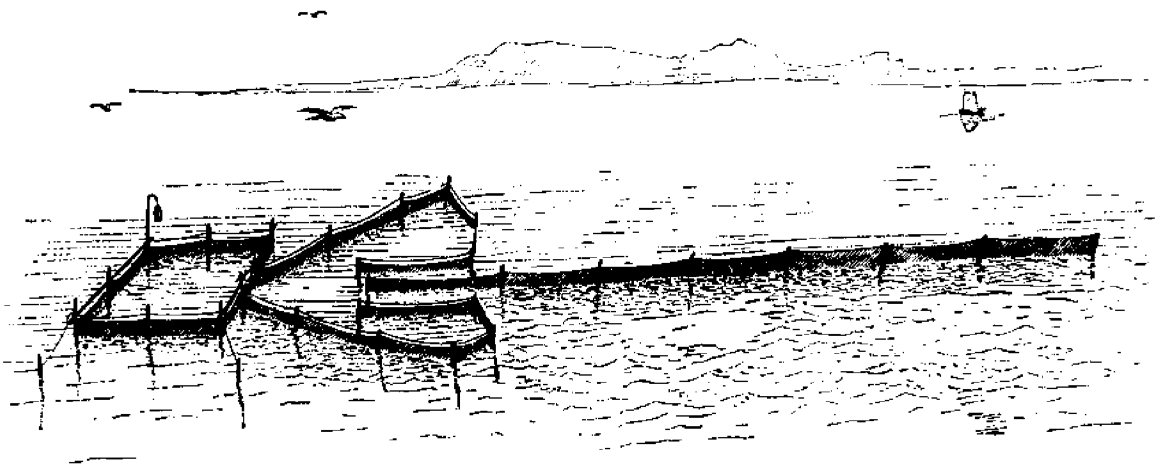


Figure 36 - Fishing Grounds of Green Bay, 1885. From Fisheries of the Great Lakes, U.S. Fish Commission, 1887.

Beginning in 1880, Escanaba was the hub of fish marketing for the northern bay. Small steamers owned by the fish processors A. Booth and Sons made regular collecting trips among the fishermen's shanty towns on Big and Little Bay de Noc. The fresh fish were taken to the Booth's "freezing house" where they were packed in ice and frozen prior to shipment to Chicago. Those fish not sold fresh were salted by the fishermen, as had been the custom for many years, and sent by steamer to Milwaukee and Chicago.

Gill netting for whitefish and some trout was also pursued several miles off shore from the Bark and Ford Rivers. Up until 1875, a fair-sized gill net fishery for whitefish extended the length of the offshore shoals from the Cedar River to the Menominee River. It supplemented the catch from the adjacent pound net fishery.

Pound nets (see Figure 37) were numerous in the shallow water areas of the northern bay from about 1867 onward. Catches from these nets were abundant for about 10 years, especially along the Menominee County shore. Though whitefish was the prize species, some lake trout were caught and herring were also taken in considerable numbers (Table 31).



GREEN BAY POUND-NET.
Drawn by L. Kumlien.

Figure 37 - A Typical Pound Net. Fish are diverted by the fence-like net on the right into the trap area at the left. From Fisheries of the Great Lakes, U.S. Fish Commission, 1887.

The Michigan bays — Big and Little Bay de Noc — are deep and large enough to offer habitat to both the cold water and fresh water fish. Pound nets on the western shore of Big Bay de Noc took whitefish primarily. Nets on the eastern side caught trout. Nets set further up the bay and near its head at Ogontz Bay and Fish Dam River caught large numbers of sturgeon, wall-eye pike, herring, perch, suckers and black bass.

Little Bay de Noc was most important for its warm water fishery, particularly for wall-eye pike, pickerel, and sturgeon. Some trout and whitefish were caught in gill nets off the mouth of the bay. The catch of ten pound nets in this region in 1884[3] was:

Whitefish	-	67,297	pounds
Trout	-	1,192	"
Dories	-	30,856	"
Sturgeon	-	11,321	"
Herring	-	42,592	"
Perch	-	400	"

Regarding the early fisheries in southern Green Bay, a U.S. Fish Commission reporter wrote in 1885:

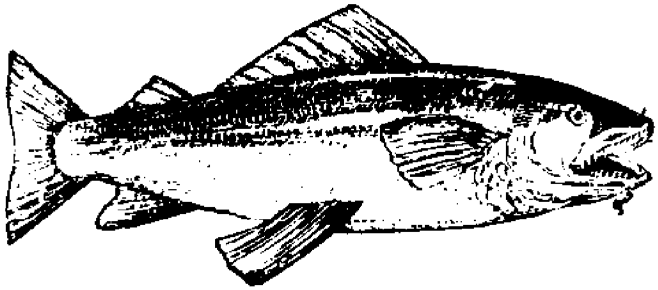
> "That part of the shore of Green Bay which extends from the Menominee River to Green Bay City ... is one of the most important fishing centers of Lake Michigan. It is flanked along its whole length by shoals of 5 to 18 feet in depth, which extend from 2 to 5 miles from the land and furnish an opportunity for the setting of pound nets in almost unlimited numbers."[4]

The general economic importance of this area probably had as much to do with the many fish wholesale houses and fish-related businesses in the region as did catch of fish. This piece of coastline was an active lumber producing area, was fairly close to Green Bay, and had direct connection to Chicago via the railroad. Unlike the northern fisheries which counted heavily on the salted fish, most fish — except herring — were sold fresh in the southern bay. Many of the fishermen owned their own businesses and were described as comfortably well off (Figures 38 and 39).

Several miles off the Marinette County shore there was considerable gill net fishing through the ice in winter for whitefish, lake trout and herring. Pound nets were the main mode of capture in spring and fall. Originally highly productive of whitefish, the nets caught practically none after 1881. At about the same time wall-eye pike catch began to decrease. The important species then became herring, perch, suckers, pickerel and sturgeon.

In Oconto County also, a few gill nets were used in winter for whitefish and herring, but the pound net fishery for herring was by far the most important. In 1885 Oconto County was the largest herring producer on the bay. (Table 31)

South of the Pensaukee River, seines and fyke nets were common. They were well-suited to fishing the shallow marshy sloughs and sandbars. Catfish



C. W. Streckenbach & Co.

PACKERS AND SHIPPERS OF

FRESH, SALT and SMOKED FISH,

No. 881 CEDAR STREET,

Corner Van Buren Avenue,

Green Bay, Wisconsin.

Green Bay is one of the chief centers on the upper lakes for the packing and shipping of fresh, salt and smoked fish, its great natural advantages near the best fishing grounds placing it in an excellent position for the active prosecution of the industry. The largest and best known packers and shippers is the firm of C. W. Streckenbach & Co., whose office and plant is at 881 Cedar street, on the corner of Van Buren avenue. The firm occupy a large area of ground, and have a most complete equipment and facilities for handling and shipping their supplies. The firm adopt the best known methods for the curing and packing of Green Bay, Lake Michigan and Lake Superior white fish, trout, yellow pike, bass, pickerel, perch, cat fish and others, and are in continual receipt of large orders from all parts of the United States for these goods. The high quality, delicious flavor, and superior condition of the fish handled by this house is well known everywhere, and their brands are continually being inquired after by customers who have tested their merits. Twenty-six experienced hands and about seventy-five experienced fishermen are employed, and over every detail of the work the proprietors exercise a close personal supervision. Mr. C. W. Streckenbach, the senior partner, is a native of Wisconsin, and a young and enterprising business man. He belongs to the K. A., K. P., Tonti, and K. L., and in both mercantile and social circles enjoys the esteem of hosts of friends. His co-partner, Mr. L. C. Schilling, is also a native of this state, and has had thirty years experience in catching and handling fish. He devotes his whole energies to the promotion of trade, and is a member of the K. A.

Figure 38. From: Pen and Sunlight Sketches of the Principal Cities in Wisconsin (Chicago, Illinois: Phoenix Publishing Co., ca. 1894)

One of the leading representative shippers and wholesale dealers in fresh lake and river fish, also smoked and salt fish in this city is Mr. L. G. Schiller, manager of the firm of C. Schiller, who has been identified with the busiuess a long time, and who has been established at the foot of North Jefferson street for the past three years. Mr. Schiller is a progressive business man, and by his energy and enterprise, has built up an immense trade, which is widely diffused throughout Illinois, Colorado, Nebraska, Wisconsin and Michigan He is admirably equipped for all purposes of his business, and occupies two spacious, commodious buildings, which are utilized for packing and shipping, cold storage, freezing rooms, etc. He employs from ten to twenty hands, and orders are filled at the shortest notice He receives daily all kinds of fresh river and lake fish direct from the nets, and he deals in every variety of salt and smoked fish. With his ample facilities, Mr Schiller can fill orders of any magnitude for fresh white fish, trout lake herring, perch, green or frozen, also pickerel, pike Menominee white and blue fins, sturgeon, black bass, etc at the lowest market prices He guarantees the best satisfaction. Mr. Schiller is a native of Germany, and came to Green Bay in 1872 He is a member of the Royal Arch and Tonti. He has always enjoyed a high reputation, and throughout his business career has shown himself to be a most able gentleman, and thoroughly conscientious in every way.

THE facilities enjoyed in Green Bay for the packing and shipment of fresh, salt and smoked fish are so great that the business is active, and engages the attention of men of experience and ability. Among the leading packers is Mr J S Johnson, whose establishment is located at the East end of East River Main street bridge This gentleman began the industry seven years ago, and has developed it to large proportions, and achieved such a high reputation that orders are continually coming in from all parts of the United States, and there is a general desire expressed among consumers to obtain his brands The plant is very extensive, embracing a new two-story packing house, 20x80 feet in dimensions, with a cold storage and ice house in the rear, 80x80, the whole being equipped in first-class style for the active prosecution of the business. Mr. Johnson handles Lake Superior white fish, bass, pickerel, cat fish, perch, etc., and adopts the latest and best methods in curing them for shipment. He employs two experienced hands, and attends personally to every detail of the business. Mr. Johnson is a native of Denmark, who came to Green Bay in 1868. He is a gentleman of middle age, a member of the I. O. O. F., and enjoys the confidence and esteem of a large circle of friends, both in a social and business way.

Figure 39. From: Pen & Sunlight Sketches of the Principal Cities in Wisconsin (Chicago, Illinois; Phoenix Publishing Co., ca. 1894.

TABLE 31

COMMERCIAL CATCH OF 1885

Region	White Fish	Lake Trout	Sturgeon	Herring	Pike & Pickerel	Salted Suckers	Miscellaneous
Big Bay de Noc	417,078	343,763	99,192	47,715	17,731	33,000	17,000
Escanaba	254,914	29,563	24,588	120,466	60,000	---	28,763
Menominee County	86,300	30,700	7,209	801,500	13,200	15,000	1,000
Marinette County	135,500	7,500	55,000	320,000	27,000	---	7,000
Oconto County	57,730	18,900	27,505	882,400	71,204	25,000	176,400
Suamico to Green Bay	---	---	2,200	360,000	365,000	5,000	150,000 catfish) 450,000 perch) 245,000 suckers)
Bay Settlement to Namur	147,000	33,445	58,450	13,570	92,725	---	---
Sturgeon Bay & Canal	169,060	66,625	6,900	55,060	1,500	---	4,500
Sturgeon Bay to Death's Door	246,365	131,360	3,000	43,125	6,650	---	---
Washington Island	85,400	35,000	---	---	---	---	---

From Smith and Snell, Report of the Commission for 1887, U.S. Commission of Fish and Fisheries (1891), p. 82.

and suckers were caught in large numbers, especially in the Fox River. Also caught in the river and offshore from Green Bay City were perch, wall-eye pike, pickerel, herring, suckers, carp, catfish, muskellenge, black bass, bull-heads, white bass, crappies, sunfish and shad. However, "not one whitefish had been caught within 17 miles of Green Bay City since 1882".[5]

In 1885, Green Bay's oldest fishing communities on the Door Peninsula were feeling the effects of overfishing. Though their catches of whitefish that year were among the highest on the bay, the fishermen complained of reduced numbers of fish compared to previous years.

The decline was particularly noticed around Chamber's Island, Fish Creek and Washington Island. After peaking in 1878, the fish catch was subsequently maintained at fairly high levels by using deeper nets with larger and finer mesh. As a result, more trout were caught and larger whitefish were taken. These fish were generally salted.

In southern Door County, most fishermen were also farmers who operated pound nets at intervals. Pound nets set off Little Sturgeon Bay and slightly to the south of it, caught whitefish and herring as well as rougher fish. At Little Sturgeon, gill net fishing through the ice for whitefish was also important.

Different from other parts of Green Bay, the Sturgeon Bay fishery increased in the 1880's. This was the result of new currents created by the completion of the Sturgeon Bay ship canal in 1882.

> "(It) caused a wonderful increase in the quantity of fish and gave rise to important summer fisheries in the waters which they affected."[6]

Between 1882 and 1885, pound nets around the mouth of Sturgeon Bay caught enough fish to keep two local fish wholesalers in business. Where previously there had been no fishery of note, a substantial fresh fish market was developed.

6.2 Exploitation of Stocks and Pollution of Habitat

From the above descriptions of Green Bay's early fisheries, it is apparent that valuable commercial species were once far more abundant and widely distributed than at present. Table 31 shows the annual catch for Green Bay fisheries in 1885. Herring and whitefish inhabited the shoals throughout the bay. Trout occurred in the deeper, colder waters of the northern bay. Wall-eye pike, pickerel, sturgeon, suckers, various bass, perch and catfish swam the shallow marshy waters at the heads of bays and mouths of rivers.

This distribution began to undergo changes as early as 1850 when stocks of whitefish showed noticeable decline in certain parts of the bay. These declines may have been due to seasonal changes in the fish's environment, but more likely they were caused by overfishing of localized fish populations.

The whitefish, like the bay's other coregonid species, occurs in distinct stocks or populations which tend to remain in their respective locales or basins. Smith and Van Oosten[7] (1940) showed in a tag-and-recapture study that 70% of tagged lake herring and whitefish were recaptured within 10 miles of their initial capture point. This relative immobility of the chub, herring and whitefish stocks partially explains their disappearance from some areas and relative abundance in others. Fishermen who located a large stock would simply fish it until it was used up.

Pollution was also a factor forcing changes in fish populations. Though pulp mill pollution was the source in the twentieth century, lumber mills were the source in the nineteenth century. A report of the U.S. Fish Commission (1887) described the pollution situation in 1880:

> "The establishment of sawmills upon Menominee River and the consequent deposition of great quantities of saw dust in the water has effected the ruin of the fisheries in the vicinity. ... Mr. Kumlien states in his notes that during the stay in Menominee he noticed that there was always a large mass of sawdust, from 1/4 of a mile to 2 miles broad, and many miles long, floating about in the bay. According to Mr. Eveland, the condition of affairs had been much the same for many years, and the spawning grounds of the white fish for a long distance outside the mouth of the river and on either shore, north and south, have been completely ruined. It is not unusual for vessels to meet portions of the mass of sawdust 20 to 30 miles from Menominee, and the water at the entrance of the bay is often covered with it. It is said to have accumulated at the mouth of the river, forming masses in some places eight feet deep.... Pound nets set in 69 to 70 feet of water, miles from the mills, become choked with all kinds of mill refuse. Bars and shoals, once the home of the whitefish, are deserted...."[8]

Not only were the offshore fishing grounds damaged, but extensive riparian whitefish stocks such as those in the lower reaches of the Menominee River were destroyed by dams and debris. The Menominee had once been a favorite fishing ground where the whitefish returning from upstream spawning beds were caught by the thousands in large racks.[9]

As the favorite whitefish became scarcer, the nets became more numerous to the point where the fish had almost no escape. (See Figure 37). Some pound net fishermen began to use nets of a finer mesh in order to catch herring and perch as well as whitefish. However, the finer meshed nets also caught many juvenile whitefish which were tossed up on the shore to rot. One Wisconsin fish warden reported in 1890:

> Four years ago last November, while collecting whitefish spawn at the mouth of Sturgeon Bay, I saw 2,100 pounds of whitefish taken out of a net at a single lift, and out of this haul there were not fifty pounds of No. 1 fish.... a No. 1 fish will weigh a pound and a half undressed. That same fall they were slaughtered in the same proportion at Little Sturgeon and I presume around the whole bay in the like manner.[10]

In the northern bay, the whitefish remained the fishermen's prime target, although herring came to form a progressively larger proportion of the catch each year.[11] (Table 32) In the southern bay, the fishermen turned increasingly to the more abundant species such as herring, perch and suckers. Since they were close to the fresh fish market, the fishermen of the lower bay had little trouble selling these somewhat less desirable fish.

TABLE 32

Production of Commercial Fisheries in Green Bay
Michigan Waters 1891-1908 (1000's of lbs)

Year	Lake Trout	Whitefish	Herring	Perch
1891	171	78	1,515	-
1892	35	149	1,645	11
1893	174	123	2,898	32
1894	142	89	1,956	41
1895	109	72	3,413	37
1896	119	89	3,890	39
1897	176	84	6,250	114
1898	161	85	7,164	78
1899	127	112	9,606	78
1900	90	83	5,781	62
1901	168	98	5,198	83
1902	307	140	7,169	131
1903	380	228	6,153	312
1904	363	283	8,569	342
1905	382	348	5,300	499
1906	332	292	7,526	355
1907	299	292	9,300	247
1908	300	222	11,850	367

From Table 2, Hile et al., Fishery Bulletin No. 75, U.S. Fish and Wildlife Service Bulletin 54: 1-32 (1953).

The increased perch catch which began in the 1890s was especially notable off the Oconto County shore. The increase seemed due not so much to greater fishing intensity as to a natural rise in the population.

> While the whitefish and the pike has been disappearing, the perch have become enormously more abundant. Before 1882 only a few scattering ones were obtained, averaging about six to each lift of the pound net. Since then they have become more and more numerous each year, until in the spring of 1885, never less than 50 pounds and sometimes as much as a ton of them were taken at a lift.[12]

Since an increase in perch catch was also noted in the northern bay fishery several years later,[13] it is very likely that the relatively tolerant erch were simply moving into habitat which whitefish had abandoned either because of pollution levels or overfishing. It is also possible that nutrient enrichment of the waters as a result of logging activity produced phytoplankton blooms, which in turn, nourished young perch.

The lake sturgeon for a number of years had been purposely destroyed by fishermen because of the big fishes' damage to pound nets. However, around 1875, the fish was recognized as a valuable commercial species — a source of oil, caviar, and air bladders for the manufacture of isinglass.[14] The sturgeon was subsequently heavily exploited. And because of its late maturing age — females do not spawn until 22 years of age and males not until 7 or 8 years[15] — the population declined precipitously under the increased fishing pressure (Figure 40). By 1910 almost none were being caught.

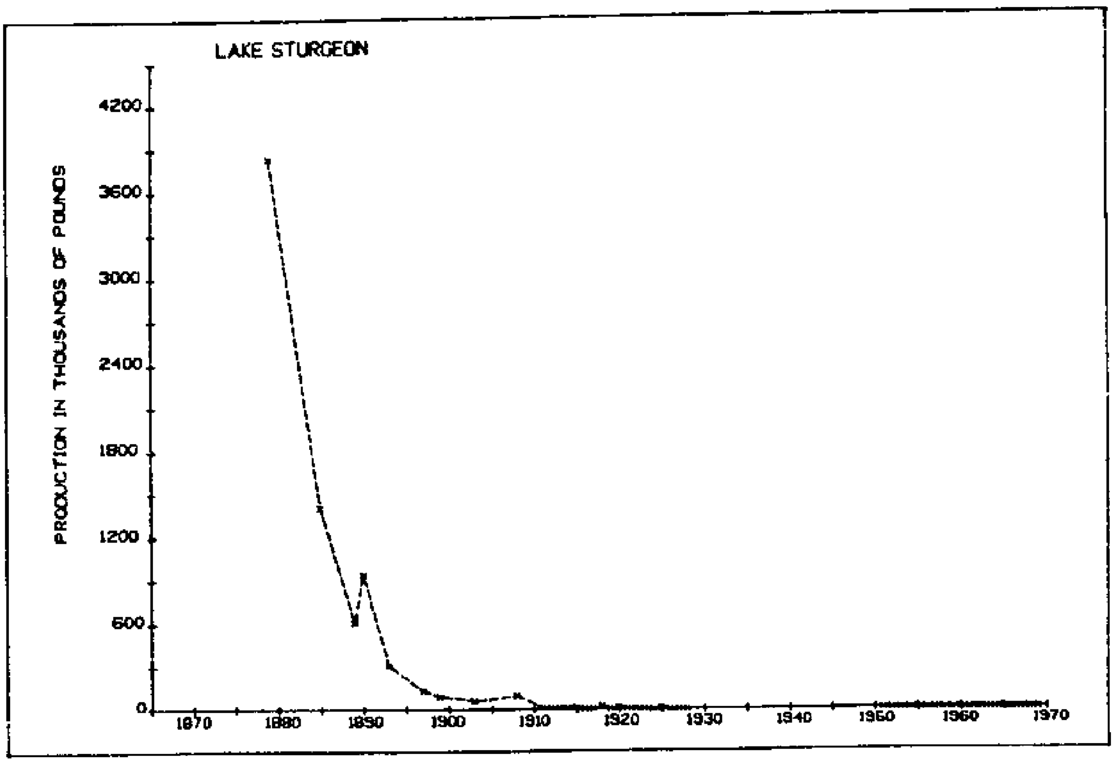


Figure 40. Commercial catch of Sturgeon in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No.20, 1973.

Plantings of whitefish and lake trout fry, begun in the 1870s,[16] continued to be made in the lake. And the U.S. Fish Commission reported in 1903:

> ...increasingly extensive fish-cultural operations on the Great Lakes have prevented the depletion of those waters in the face of the most exhausting lake fisheries in the world.[17]

Nevertheless, with the exception of a few years of improved whitefish catch, the trend in production was downward until 1925 (Figure 41). Part of this trend, of course, reflects the fact that as a species becomes scarce, fishermen will no longer try to catch it. In fact, around 1912 some gill net fishermen left the area, loading their fish tugs on flat cars and heading for other parts of the Great Lakes and the cod fisheries of the Atlantic coast.[18]

Since the early fishermen often failed to distinguish in their records between the more common whitefish _Coregonus_ and the larger species of deep-water ciscoes (chubs),[19] it is likely that part of the decline in whitefish catch may have also been a decline in the catch of the chubs _Coregonus nigripinnis_ (the "blackfin") and _C. johannae_. In at least one area of the northern bay, from a quarter to 100 percent of the whitefish taken in certain years were actually "blackfins."[20] There is evidence that _C. nigripinnis_ and _C. johannae_ were under great fishing pressure and were already declining by 1920.[21]

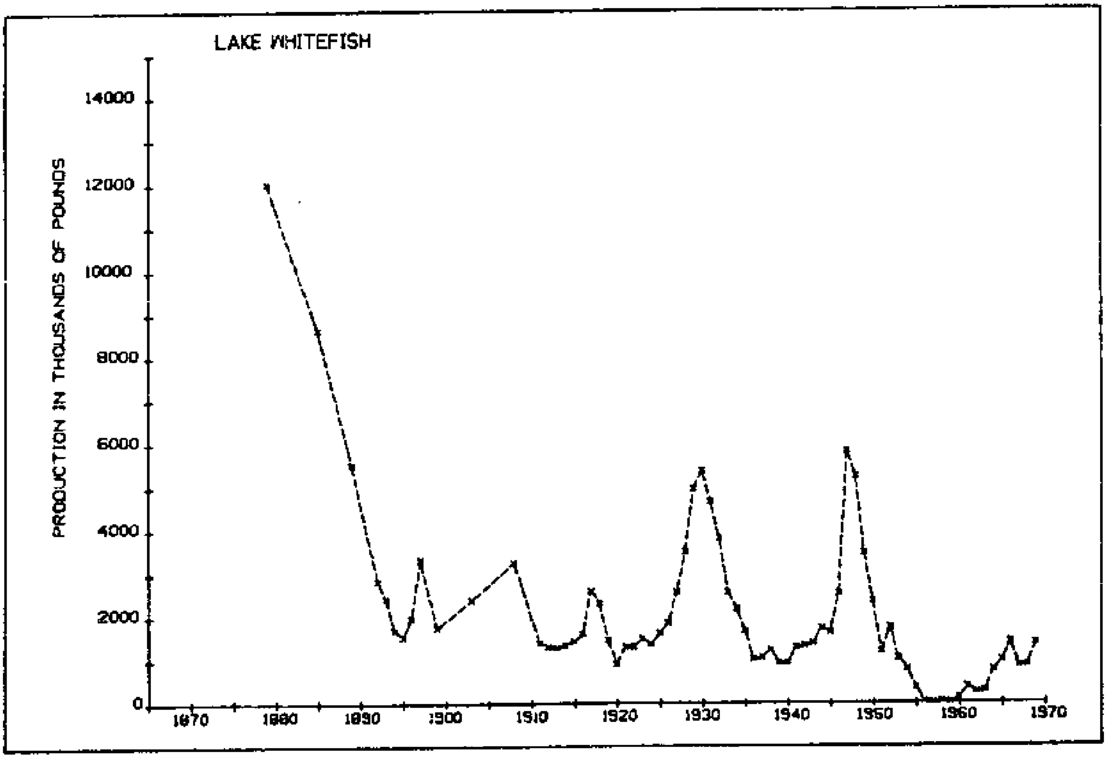


Figure 41. Commercial catch of whitefish in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 2, 1973.

By the end of World War I, the picture had changed again. Perch catches were on a decline, having peaked between 1885 and 1900. Thereafter the population showed considerable sharp fluctuations, generally in response to changes in the stocks of other species.[22] The lake herring catch also peaked around 1905 and never regained its former abundance. Subsequently, fishermen began showing greater interest in the various smaller chubs, though the size of chub catches varied widely. Around 1912 lake trout catch had also begun a slow downward trend after having held steady for a number of years.[23] The wall-eye catch continued to fall off, although there were important year class peaks in the later years. The suckers, too, which had become moderately important, reached a peak and began to decline in 1920. Figures 42, 43, 44, 45, 46, & 47 show the production changes in the perch, herring, chubs, lake trout, wall-eye and sucker fisheries through Lake Michigan, but are also representative of the changes occurring in Green Bay.

Exploitive harvesting had exerted heavy pressures on the bay's fisheries. But it was not the only factor at work. Between 1899 and 1929, the economic focus of the region had shifted from lumber cutting to manufacturing and papermaking. During those 20 years, pulpwood consumption in Wisconsin increased about 560% and most of that increase was in the Fox River Valley.[24] Moreover, the numerous mills that lined the banks of the Fox were relatively unfettered in their use of the river for power and for waste disposal.

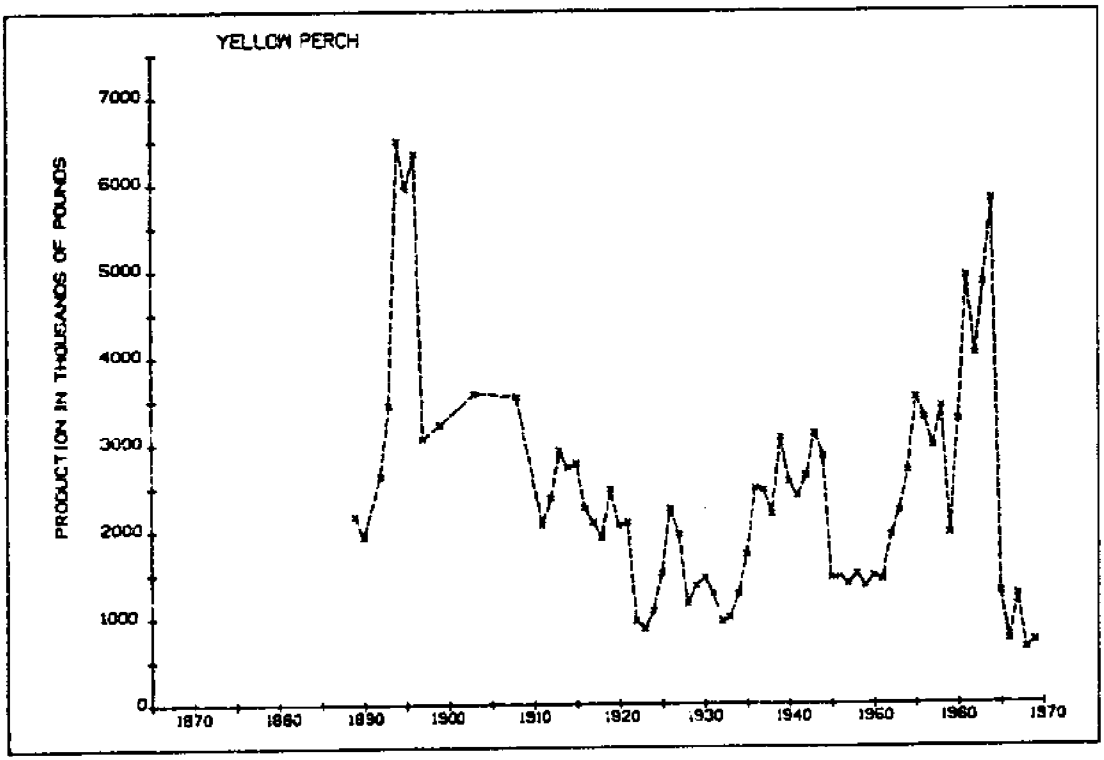


Figure 42. Commercial catch of yellow perch in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

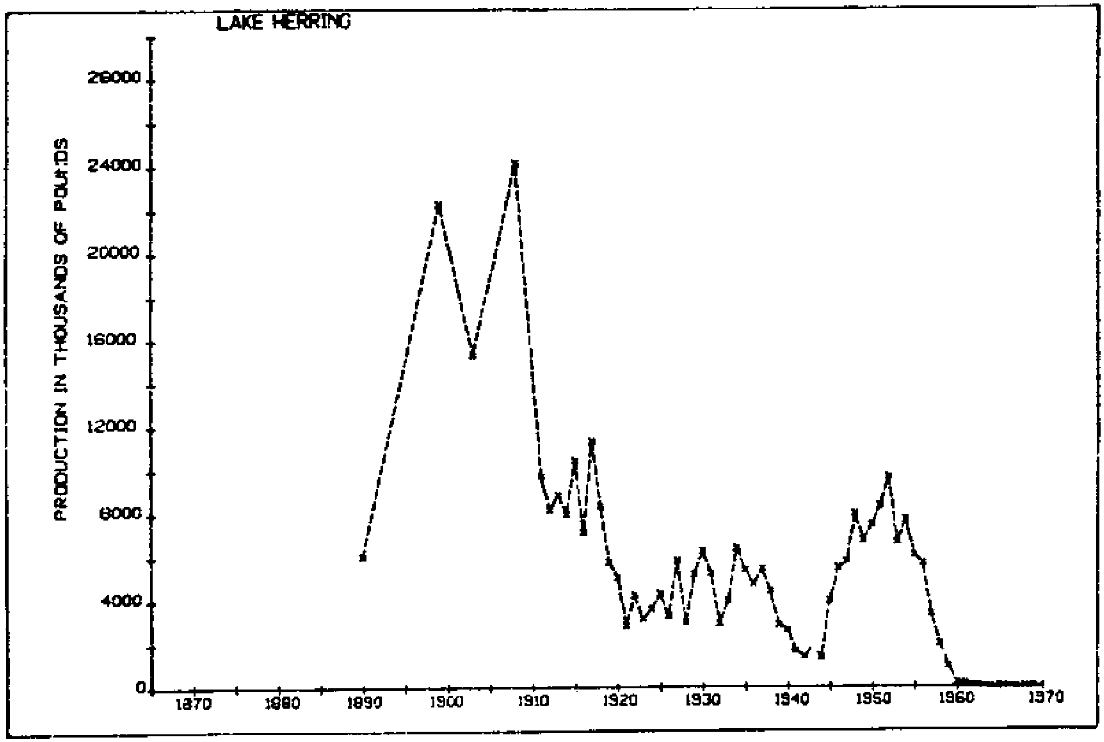


Figure 43. Commercial catch of Lake Herring in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

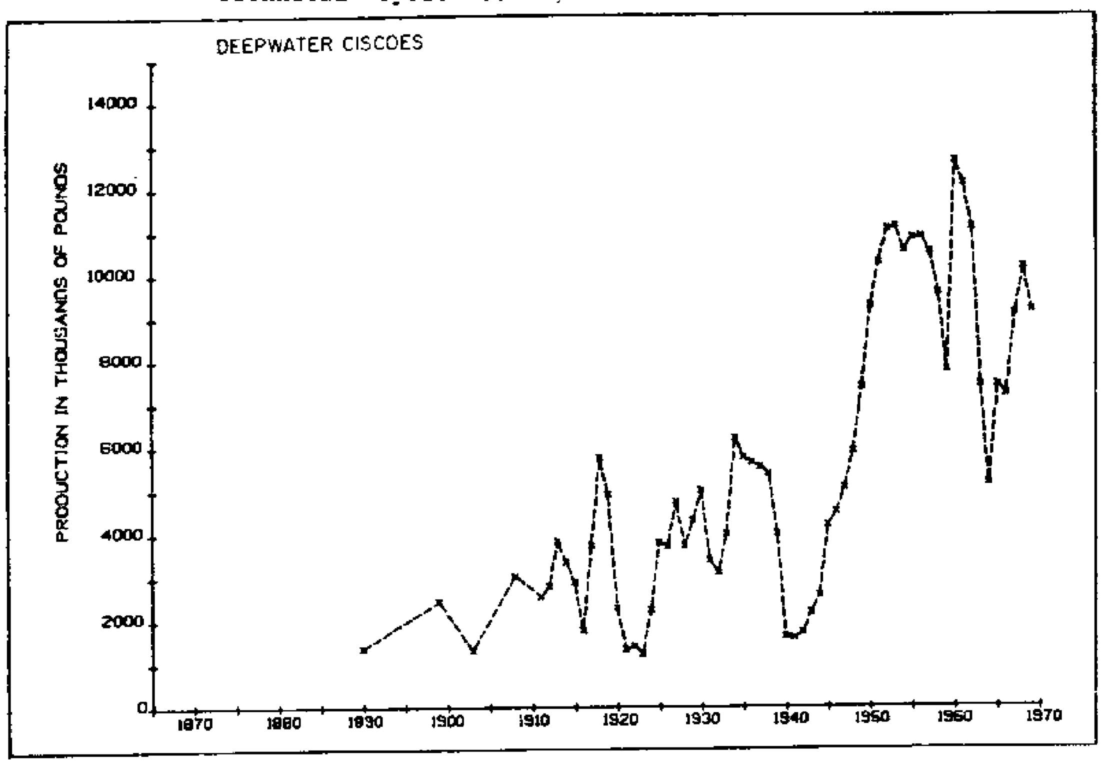


Figure 44. Commercial catch of deepwater ciscoes in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

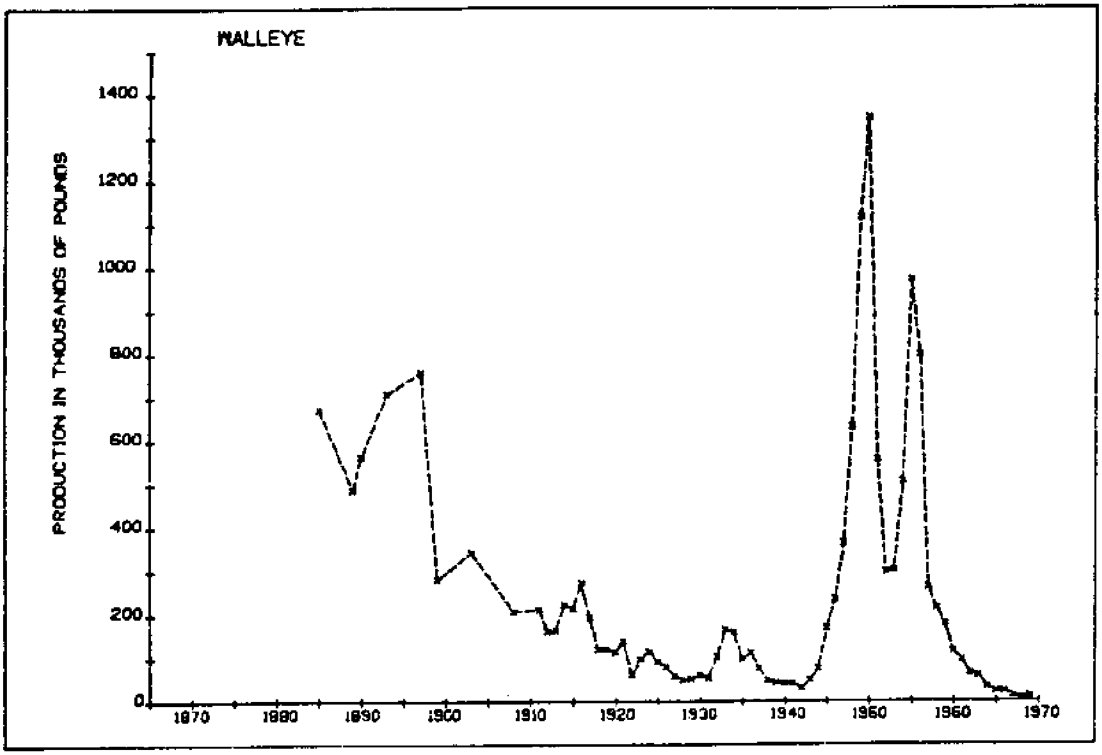


Figure 45. Commercial catch of walleye in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

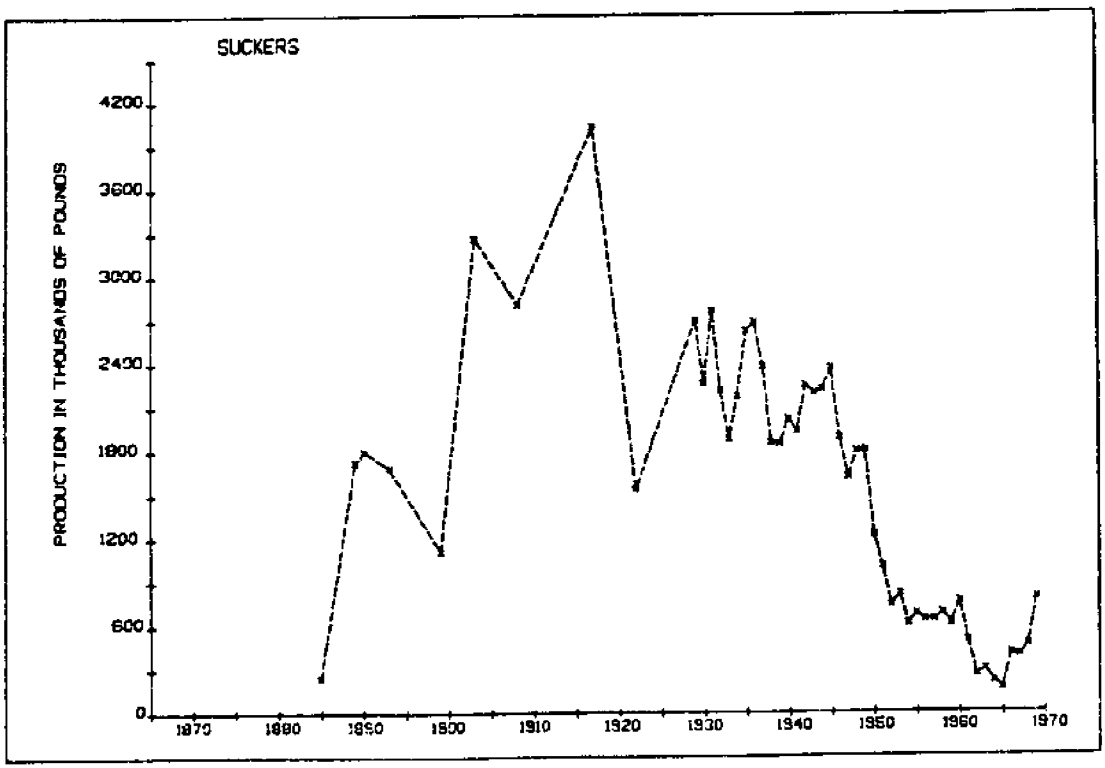


Figure 46. Commercial catch of suckers in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

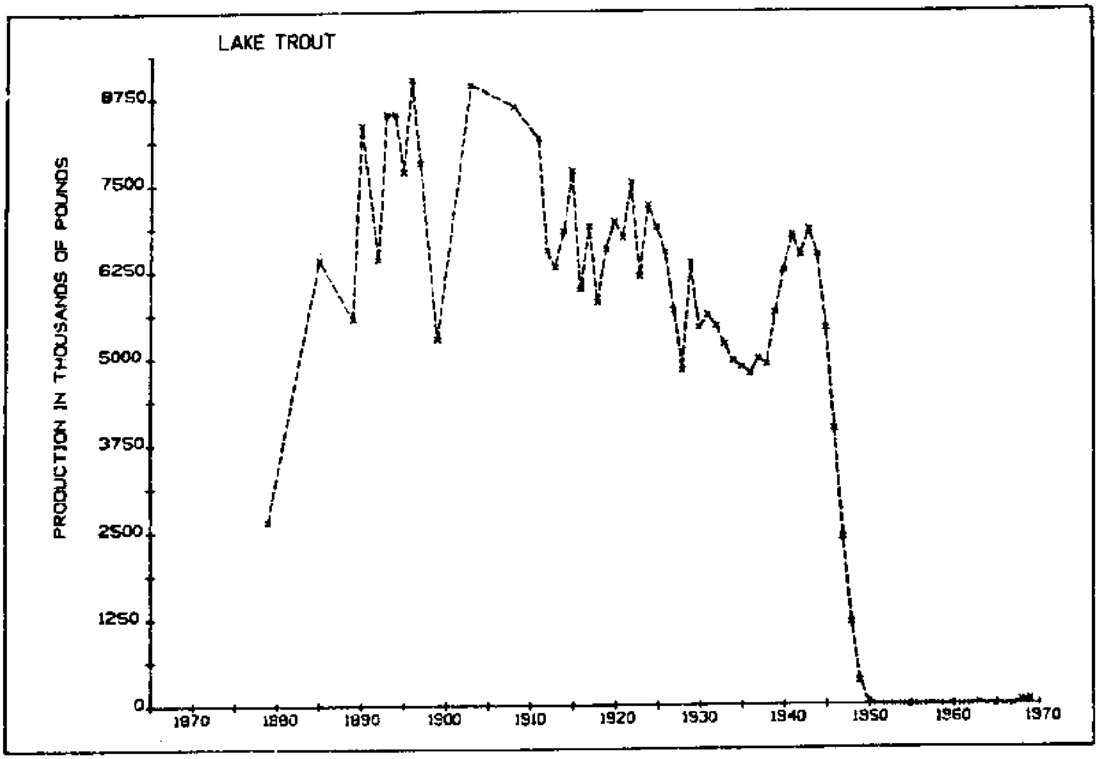


Figure 47. Commercial catch of lake trout in Lake Michigan. From: Great Lakes Fishery Commission Technical Report No. 20, 1973.

In 1927 the Wisconsin Conservation Commission and State Board of Health issued a special report decrying the damages of water pollution on the Fox. In describing the biological repercussions, the investigators stated:

> Even the more resistant fishes, which inhabit the lower regions of the river, cannot withstand the combined effects of extensive pollution, low stream flow and high water temperatures which frequently exist during the latter part of the summer and early fall. The death of a large number of fish in the section of the river from Wrightstown to Green Bay has become almost an annual occurrence.[25]

The deaths were attributed to low oxygen levels caused by untreated pulpmill wastes.

Power dams also received some blame for the general decline of river and inner bay fish populations. By restricting fish movements up the Fox, the dams had forced migrating species to spawn in unfavorable habitat near the river's mouth.[26] At a national meeting of the Izaak Walton League in Green Bay in 1925, the outdoor editor of the Milwaukee Journal dramatically described the plight of the spawning fish.

> I stood on the bridge at DePere last spring and saw the pike come down out of Green Bay. The great horde, following the old primordial instinct to find the spawn beds, ran into a man-made

obstruction -- the dam at DePere .... I watched them there for hours, constantly following that blind instinct to swim the river, and at last exhausted, dropping their spawn to be swept against the rocks and destroyed.[27]

Besides blocking the movements of migrating fish, dams also had other effects on riparian communities and ultimately on fish stocks. Habitat diversity was lost as rapids and shallows were flooded and deepened. Continual channelization of rivers, especially the Fox, increased siltation to the extent that mud became the common bottom type. Water movement slowed, temperatures rose and dissolved oxygen decreased to the point that great stretches of river behind the dams took on lake-like characteristics. In fact: "At the period of lowest water the stretches of the [Fox] river between dams are practically cut off from each other and for all practical purposes are small elongated lakes."[28]

River biota reflected these physical changes. Sensitive oxygen-demanding plants and animals disappeared and were replaced by more tolerant species. And, fish like small-mouthed bass gave way to the less desirable bullhead and sucker.

6.3 AN INVASION OF EXOTIC SPECIES

Up until 1920 the abundance of Green Bay fish stocks had been controlled by four interacting factors: man's pollution and destruction of habitat, overfishing, natural competition among species, and the vagaries of the physical environment. A fifth and critical dimension was added in the 1920s — competition from exotic species.

The first troublesome newcomer was the German carp which the Wisconsin Fisheries Commission had, with all good intent, planted throughout the state in the 1880s and 1890s.[29] This fish had reproduced and disseminated itself to a troublesome degree by 1920. It is now found throughout Green Bay, particularly along the shallow western shore. Here it roots up vegetation and muddies the waters, disturbing the habitat for other fish such as pickerel, and making the water less attractive to swimmers and fishermen.

Of greater impact on the commercial fisheries, however, was the arrival of the adaptable ocean smelt. This fish was first reported in Green Bay in 1924.[30] Escaping from a stocked lake in Michigan, smelt reproduced at a rapid rate in Lake Michigan. By 1931 Green Bay fishermen had made their first commercial harvest of smelt using nets under the ice. Catches by both fishermen and sportsmen increased each succeeding year, especially in the Wisconsin waters of the bay.[31] In 1940, a record (at that time) 6,529,543 pounds were taken from the bay. But suddenly in 1944 the population creashed, the victim of an epidemic that had killed off adults as well as the 1942 and 1943 juveniles. According to Van Oosten:

> Not only was this mortality a severe blow to all who fished for smelt...but it came at an extraordinarily inconvenient time for the nation's wartime food-production program and for the fishery officials who were working so assiduously to augment the country's food stock through a more intensive exploitation of the species.[32]

Because of the wartime circumstances and the popularity of smelt fishing, the dieoff was heavily publicized and accompanied by wild rumors. Some attributed its cause to sabotage by enemy agents while others throught it was due to gunnery practice at the naval stations. Subsequently, however, the stock recovered and even exceeded its former abundance. During the 1950s and 1960s, almost the entire commercial smelt catch for Lake Michigan came from Green Bay.[33]

The smelt which Hogman describes as sharing "nearly homogeneous environmental requirements" with the lake herring, also preyed upon that native fish.[34] Hogman's study of the fishery statistics for these two species shows that peaks of smelt production followed peaks of herring production. He interpreted this as predation by the smelt on juvenile herring. This hypothesis is supported by the notable rise in herring population which followed the 1942 smelt dieoff.[35] (See Table 33)

Whitefish populations, too, were affected by the smelt. A temporary rise in whitefish catch (1928-1932) was followed by a decline that was

Table 33. Total Commercial Catch of Lake Herring in Wisconsin and Michigan Waters of Green Bay (1,000s of pounds)

1936	3,869	1945	3,664
1937	4,102	1946	5,216
1938	3,008	1947	5,285
1939	1,501	1948	7,462
1940	1,489	1949	6,320
1941	1,300	1950	6,892
1942	849	1951	7,711
1943	1,284	1952	9,122
1944	1,005	1953	5,894

From Table 2, S. H. Smith, "Life History of Lake Herring of Green Bay, Lake Michigan" Fishery Bulletin 109, U.S. Fish and Wildlife Service Bulletin 57: 87-138 (1956).

partially blamed on smelt predation of whitefish fry.[36] This theory is supported by records of the whitefish harvest which rose dramatically in 1947 to 1949. (Figure 41 and Table 33) The catch in those years was dominated by whitefish of the 1943 year class — a class that apparently had survived and thrived in the wake of the 1942 smelt dieoff.

But the late forties whitefish peak fell as quickly as the early thirties peak, largely due to excessive harvest of the stock.

In 1936, another invader, the sea lamprey entered Lake Michigan, having wended its way from the Atlantic, through the Erie Canal into Lake Ontaria. From there the lamprey traveled through the Welland Canal and into the other Great Lakes. The parasitic, blood-sucking lamprey attacked lake trout in increasing numbers and by 1956 the last of the sleek native trout was believed to have died of lamprey wounds.[37]

The loss of the top predator from the lake's food web had immediate repercussions on the populations of prey fish. Not only was there an upswing in smelt numbers, but the newly introduced alewife multiplied in totally unchecked numbers.[38] The alewife had entered the lakes in 1949 along the same route that the lamprey had followed.

The alewife, free of predators, quickly became a problem. Fishermen first complained of large numbers of alewives in their nets in 1956.[39] Within five years that Lake Michigan alewife population had exploded. Not only did it explode, but it also died off in large numbers, creating a major nuisance on the beaches. The largest mortality occurred in 1967 when several billion fish, an estimated 70 percent of the population died.[40] Since then the population has gradually stabilized.

However, during its explosive phase, the alewife stocks had a dramatic impact on other lake fisheries. The alewife became a serious food competitor of the smelt, the chubs, and the lake herring.[41] The alewife's abilities as a "universal zooplankton consumer" gave it distinct advantages

Table 34. Commercial Catch of Whitefish in 1,000s of Pounds

	Lake Michigan[1]		Green Bay Only[2]
	Michigan	Wisconsin	Michigan Waters
1940	754	197	123
1941	896	401	116
1942	1,061	279	93
1943	1,152	254	141
1944	1,403	343	232
1945	1,326	331	234
1946	1,822	735	514
1947	4,108	1,807	2,427
1948	4,263	485	3,066
1949	3,007	259	2,263
1950	2,102	242	1,494[a]
1951	971	290	441[a]
1952	1,481	189	933[a]
1953	858	197	636

[1] Baldwin & Saalfeld, "Commercial Fish Production in the Great Lakes, 1867-1960", Tech. Report No. 3.
[2] Hile et al., (1953) "Fluctuations in the Fisheries of State of Michigan Waters of Green Bay."
[a] Stanford Smith, personal communication.

over the fry of other fish. And because it occurs in dense schools and occupies different depths of the lake at different times, it was able to compete intensively with deep as well as shallow water species.[42] The lake herring fry, already being preyed upon by smelt were reduced to almost insignificant numbers by the alewife. Even the smelt could not compete with the alewife. Smelt catch fell off considerably between 1959 and 1965.[43]

The death of the lake trout population also effected whitefish stocks. With the loss of their preferred hosts, the lamprey turned to whitefish as a second choice, inflicting heavy mortalities. From 1956 until after 1965, when lamprey control programs took effect and lake trout were re-stocked, the whitefish populations remained low.[44]

The alewives and lampreys together seriously effected chub stocks. Between 1955 and 1960 the bloater chub peaked in numbers, filling the niche vacated by larger chub species which had declined under the pressures of overfishing and lamprey predation.[45] However, since the 1960s the bloater catch has been steadily falling off, the result of competition from alewives. The present bloater catch consists almost entirely of larger, older fish, of which 65% to 95% have been females. According to Stanford Smith, these exact conditions were observed in the bloater club fisheries of Lakes Huron and Ontario before the fisheries collapsed there.[46] Edward Brown, Jr. states:

> In fact there is no real evidence anywhere that bloaters and the other deepwater ciscoes can sustain themselves in the presence of large populations of alewives (and possibly smelt). Drastic changes in the fish stocks of Lakes Huron and Ontario suggest that the ciscoes are incompatible with, and are eventually replaced by, the non-native competitor species.[47]

The alewife and lamprey invasions into Lake Michigan were repeat performances of the fishery destruction that had occurred in Lake Ontario at the turn of the century.[48] The story was the same, only the scene had changed. The alewife had first entered Lake Ontario in the late 1800's after the Atlantic salmon had died out as a result of pollution and intensive fishing. Simultaneously sea lampreys entered Ontario and destroyed the lake trout and burbot. In the absence of predators, alewives exploded, competing with commercial species and destroying the fishery. The alewife population eventually ate itself out of food and collapsed. But unfortunately the survivors were able to navigate the Welland Canal and thrust themselves upon another lake system.[49]

Throughout the 1950's and 60's Lake Michigan's — and Green Bay's — fisheries could only be described as ailing. The biological system was out of balance. Its condition was not helped by the fact that pulp and paper and other manufacturing industries of the Fox River Valley had continued to expand production, that population in the watershed's cities had continued to grow, and that effluent and pollutant loads had increased proportionately. The fisheries faced an uncertain future.

Stanford Smith who has carefully followed the history of alewife, lamprey and commercial fishery interactions, states that a comprehensive rehabilitation program for Lake Michigan depends on the "re-establishment of large piscivores and the restoration of an interacting multiple species complex of minor piscivores, and deep and shallow water planktivores."[50]

He further explains that adequate sea lamprey control is the first step to permitting successful establishment of lake trout and other salmonids. This population, in turn, will control alewife numbers. But, for stability, Smith believes the system needs more "actors":

> Maintenance of high predator productivity will, however, depend on the restoration of an interacting complex of forage species that will occupy the entire lake efficiently. As alewife stocks are reduced, other forage fish must be available. Early or easy attainment of this phase of counteracting the unfavorable influences of alewife are very uncertain. Since lake herring and emerald shiners were reduced greatly when alewife abundance was very low, their return may require extreme reduction if not

virtual elimination of the alewife. The greatest requirement, however, will be the restoration of populations of chubs to occupy the vast deepwater regions that represent 70-80% of the area of those Great Lakes (Michigan, Huron, and Ontario) which have been seriously affected by the alewife. ... Restoration will be slow in lakes where the fishery balance has been upset and productivity reduced by combined influences of the sea lamprey and alewife. The initial period of severe reduction of alewives by establishment of predators, or by commercial exploitation, or both, will be a period of good productivity of large predators. As alewives become greatly reduced, there should be early recovery of at least some shallow-water planktivores and minor piscivores that live in nearshore areas and bays, but there may be a time lag of one to several decades before chubs become abundant in the vast deepwater regions of the lake.... recovery of bloater stocks would require at least a decade and probably more, and development of a multiple species coregonid complex occupying the entire deepwater region comparable to the past, may require many decades or centuries. Recovery of chubs in Lake Ontario would very likely require significant reversal of the progressive enrichment, or the introduction of coregonids from other areas of the world that tolerate deep, rich lakes if, indeed, such species exist.

The repopulation of the deepwater regions will be the most critical period of fishery restoration. Populations of major predators cannot be high during this period because they would slow or possibly prevent re-establishment of native or introduced deepwater coregonids. Thus, productivity of major predators would probably be low, although not as low as during the period of maximum abundance of sea lampreys. The previously abundant inshore species such as smelt, emerald shiners, and yellow perch should recover sufficiently to provide forage for larger inshore predators such as brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdneri*), but open lake predators such as lake trout and Pacific salmon could be seriously affected by a shortage of food.

Lower fishery productivity than at present appears inevitable in the process of fishery restoration in Lakes Michigan, Huron, and Ontario, and possibly in Lake Superior. The degree and period of low productivity will be reduced if stocks of deepwater predators do not become excessive during the period when alewives decline and coregonids are being restored. To accomplish this transition without a complete collapse of fish stocks, including even minor forage species, will require judicious manipulation of the fisheries and predator stocking rates, because sufficient predator abundance must be maintained to suppress alewives but allow recovery of deepwater prey species. Indeed, it is impossible to anticipate if this can be done — if it cannot, the alternative would be to overstock the lakes intentionally with large predators in an attempt to eliminate the alewive — creating conditions similar to those that prevented alewive establishment in Lake Ontario before 1850 — then restoring the forage fish by introductions in the near absence of major predators. Success in this approach would require a major effort to attain rapid restoration of sufficiently large stocks of forage fish to support enough major predators to prevent re-establishment of the alewife.[51]

Intensive effort was put into programs to control lampreys, beginning in the early 1950's.[52] Eventually a system was devised of electric screens, which shocked adult lampreys coming upstream to spawn. Subsequently, a more efficient system of chemical treatments was derived to kill young lamprey larvae. As the control program showed signs of success, restocking of lake trout began. The first plant of 1.2 million fish was made in 1965. Since then millions of lake trout and coho salmon have been planted each year.[53] More recently, Chinook salmon have also been introduced.[54]

In the meantime, some commercial fishermen on lower Green Bay have found the alewife to be a profitable catch. Table 35 and Figure 48 show the rapid rise in alewife catch between 1956 and 1970. It is estimated that until 1970 the harvest of alewives took a very small part of the total population,[55] 18.6 percent (Table 35). Since the alewife fishery began, Green Bay harvests have comprised from 50 to 85 percent of Lake Michigan's total alewife catch.[56]

Table 35. Commercial Landings of Alewives in Lake Michigan 1956-1970 (thousands of pounds)

Year	Trawl	Poundnet	Other Gear	TOTAL
1956	--	a	a	a
1957	--	185	36	220
1958	55	1,241	61	1,356
1959	59	1,057	149	1,264
1960	526	1,787	57	2,370
1961	2,048	1,121	29	3,199
1962	2,309	2,381	53	4,742
1963	3,493	1,897	6	5,396
1964	7,760	3,969	14	11,743
1965	11,420	2,556	32	14,007
1966	18,548	10,424	30	29,002
1967	19,535	22,338	23	41,895
1968	13,085	13,791	318	27,194
1969	14,226	14,839	183	29,248
1970	15,411	17,997	52	33,461

a = less than 500 lb.

From: "Population Biology of Alewives Alosa pseudoharengus in Lake Michigan, 1949-1970." Edward H. Brown, Jr., Journal of Fisheries Research Board of Canada 29: 478-500, (1972).

Table 36. Commercial Production of Alewives as Percent of Available Fish

1963	0.8- 1.8
1964	2.4- 5.2
1965	1.2- 2.8
1966	1.4- 3.0
1967	1.7- 3.7
1968	2.5- 5.4
1969	8.7-18.6
1970	5.5-11.7

From E. H. Brown, Jr. Journal Fish Res. Board of Canada 29:498 (1972)

The alewife harvest is distressing to some sports fishermen who see it as a threat to the potential supply of prey food for salmon and lake trout.[57] There is a belief by some fishery biologists thatthe alewife population will decline to much lower numbers and probably will not sustain continued harvests of the present size. One biologist speculates:

> ... it may be hypothesized that the collapse of the alewife population in 1967 in Lake Michigan ... was due in part to its grazing habits; and its lack of recovery may have been caused by the extermination of nutritionally important zooplankters by the alewife, while leaving the less valuable ones to reproduce.... If (this) did happen, then the possibility exists that the alewives will not recover as long as they have no "beefsteak zooplankters" for food. Consequently, the alewife may be operating on a very small food base out of all of the zooplankton in Lake Michigan. Another bad recruitment year or more intensive salmonid predation could trigger another more serious collapse which in turn would cause a decline in the salmonid populations in the lake.[58]

In fact, Edward H. Brown, Jr. believes that mortality from salmonid predation may have already surpassed fishing mortality and that predation is now "a significant factor in alewife survival."[59]

Other biologists argue equally strongly that the alewife is in no danger of depletion by either fishing or predation. This controversy merely emphasizes how little is actually known regarding the size of alewife populations.

It is questionable whether the further "judicious manipulations" of the fisheries suggested by Smith are possible. When lake trout and salmon stocking programs began, the stated intents of state of Michigan fisheries people was to make the lake a sports fishery. At the time this decision was made, the economic impact of commercial fishing had fallen off and the recreation dollar was becoming increasingly important. In the words of Wayne J. Tody, Chief of the Fisheries Division of the Michigan Department of Natural Resources:

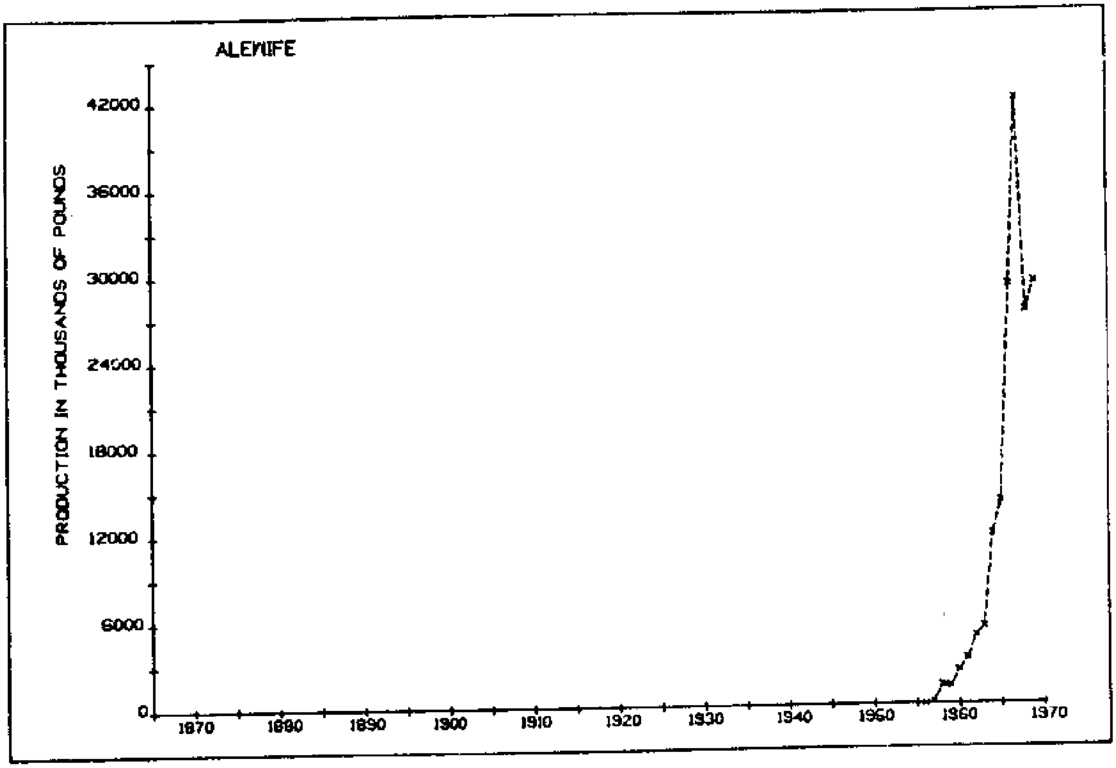


Figure 48. Commercial catch of alewife in Lake Michigan. From: Great Lakes Fishery Commission, Technical Report No. 20, 1973.

> To save, restore, and enhance the fisheries of the Great Lakes we must apply positive action — research, planning, investment and management. .... Perhaps tens or even hundreds of millions of dollars will be added to Michigan's economy in the next few years if a trout and salmon recreational fishery can be developed to meet an overwhelming public demand.[60]

Subsequently, sports fishing has been successfully promoted in all the bordering states of Lake Michigan and the commercial harvest of salmonids has been banned and, in the state of Michigan where the sport fishery is now valued at 20 million dollars a year,[61] the commercial fisherman has been systematically eliminated by restrictive legislation:

> In 1970 .... a zone management program and limited entry were put in effect in an attempt at effective control of the commercial harvest. Under these new regulations, part-time fishermen were eliminated from the fishery and the number of licensed commercial fishermen reduced from approximately 300 to 188.... (In 1964 there were approximately 1,000 commercial fishermen in Michigan.)
>
> ... The future holds some radical changes for commercial fishing in Michigan. The Department of Natural Resources is proposing that gill net fishing (except for carp) be prohibited by 1974, and that all fishing be done with impounding gear.... It is further proposed that all fishing be done under some form of contract. The contract form of management will reduce the number of operators to about 40 and should put the industry on a sound economic basis.[62]

The most recent effort in this direction, a ban on gill net fishing in all state of Michigan waters, of the Great Lakes as of January 1, 1975, caused Wisconsin in August 1974 to rush into effect a closure on the issuance of commercial fishing licenses.[63] The intent was to keep Michigan gill netters from flocking to Wisconsin waters and increasing the pressures on commercial stocks there.

Michigan's ban on gill nets and Wisconsin's penalties for commercial catch of lake trout have caused much bitter feeling. In Michigan, whitefish gill net fishermen have been forced to give up fishing or change to pound net fishing, an expensive conversion. In Wisconsin whitefish gill netters feel harassed because they are continually watched to see that their incidental catch of trout does not exceed the legal limit. On Michigan's upper Peninsula it is common to see bumper stickers which read "Support Your DNR— With A Rope" and "What the Lord Giveth, the DNR Taketh Away."

If current signs are accurate, the sports fisherman has become a strong political force that not only opposes commercial fishing interference but may just as vigorously oppose any management measures that will reduce the present abundance of salmonid game fish — even if the reduction is necessary for the ultimate return of a balanced and self-sustaining ecosystem.

Aggravating the conflict between sport and commercial interests is the fact that the salmonid fishery is presently a put-and-take operation. The coho and chinook salmon cannot spawn in the Midwest's silty streams and, for unknown reasons, the lake trout have failed to reproduce themselves. When the first hatchery-reared lake trout adults spawned in 1971, they showed decidedly different behavior from that of previous native populations.[64] The early populations were known to spawn at depths of 10 to 40 or more fathoms on clay bottoms or rocky reefs. In 1971, the stocked trout spawned in water depths of 30 feet or less and laid their eggs indiscriminately on all bottom types.

Samples taken by trawler the following year failed to turn up a single young-of-the-year lake trout. Though the trout is known to be elusive in its first year, these discouraging results suggested that hatch survival was extremely poor. The eggs were known to be viable since eggs taken from the 1971 spawn and kept in the GL Fishery Lab hatched well.[65]

It is suggested that the stocked lake trout is not as finely tuned to the lake's environment as the native fish was. LaRue Wells of the GLFL has said, "Although the native trout in the lake before the invasion of the sea lamprey obviously reproduced successfully under thermal conditions similar to those now present, it does not necessarily follow that stocked fish can be expected to do likewise. One might speculate, for example, that inadvertent selection in the hatchery has developed strains of trout with incubation times not conducive to successful reproduction in the lake."[66] It is also suggested that the fish have not reproduced because the fry were not planted on the traditional lake trout spawning grounds.

As of 1974, lake trout were still not reproducing themselves. Both the salmon and lake trout populations remain dependent on yearly restocking programs. And, regardless of who harvests the fish, for the present the salmonids are there only by the grace of state and federal tax revenues.

Wisconsin's intent to limit chub fishing by limited entry, quotas, or closure[67] and to encourage alewife fishing seem in line with Smith's suggested programs for managing a more stable fishery. Yet it is not clear whether Wisconsin or Michigan, the major proprietors of Lake Michigan, actually have long range plans for establishing a multi-species ecosystem. Nor is it clear to what degree the two states are coordinating their actions or plans. Finally, it would appear that no attempt is being made to inform the general public as to how fish management plans will effect the availability of fresh fish for food consumption in the long and short run.

6.4 THE COMMERCIAL FISHERY TODAY

Today the Green Bay commercial fishery depends largely on the harvest of less desirable species for fish meal and other purposes. Even the Fox River supports a small fishery of rough fish. Lawrence Van Lanen, commercial fisherman on the Fox, uses 8 fyke nets set in the river north of the DePere dam. His catch in 1973 consisted of 33.7% bullhead, 29.7% carp, 14.2% sucker, 7.5% black crappie, 4.6% fresh water drum, 3.9% white bass and 7% of some 17 assorted species.[68] Some of the fish are sold to the fresh fish market and some go to a local soap company.

That carp and other rough fish are now the major piscine inhabitants of the lower bay was verified in 1973 when the DNR set trap nets in lower Green Bay south of Long Tail Point. The catch was almost entirely carp. The abundance of carp in the bay and the disturbance they cause to rooted vegetation, benthic invertebrates, and other fish certainly deserves attention. Perhaps a harvest of carp might prove beneficial to the lower bay in several respects.

The alewife fishery in Green Bay is centered on the west shore and accounts for more than half of Lake Michigan's total alewife catch.[69] The fish are caught in pound nets and by trawler. The pound nets are set in 12 to 15 feet of water in the offshore areas north of Pensaukee. Alewife trawlers fish in 30 to 40 feet of water, about six miles off the west shore and three miles off the east shore. The southern limit of the trawls is the entrance light at Green Bay harbor.[70]

A fish processing plant at Penaukee operated by Art Swaer and Son currently handles a large part of the bay's alewife harvest. Swaer owns 6 trawlers, two of which are the first new fishing boats to be built in the Upper Great Lakes region of the U.S. in many years. Swaer's plant processes up to 15 million pounds of alewives a year for pet food (Friskies and Kalcan products) and about the same tonnage for fish meal supplement for animal feeds.[71] At the peak of the spawning season (July 4) the plant handles 500,000 lbs/day, including alewives bought from other fishermen. Other alewife processing centers on the bay are at Escanaba, where 27,000 lbs/day are handled during the season, and at Menominee where 100,000 pounds are processed. UW food scientists are investigating the prospects for a canned sardine-line alewife product for human food. Preliminary results are promising.[72]

Perch have been taken in increasing numbers in the lower bay in the last two years by trawlers and gill nets. In July of 1974 one fisherman in the Pensaukee area was catching 400 to 700 lbs of perch per lift of his gill net — a better catch than seen in many previous years. A number of observers speculate that the perch population has returned to the lower bay following the flushing action of high water levels. In this light, the return of the perch would appear to be only temporary and not a sign of actually improved water conditions. However, it is also possible that the perch population has increased as the harvest of alewives has become more intense and reduced the heavy competition from that prolific fish.

Lake herring are fished during October and November at depths of 20 to 50 feet. During the winter months, smelt are fished along the west shore of the bay.

In the northern bay, alewives as well as whitefish are fished from the Marinette-Menominee and Escanaba regions. Most of the fishermen in northern Door County fish pound nets and gill nets for whitefish and some chub. Two of the fishermen in the Gills Rock-Washington Island area have licenses to use gill nets in Michigan waters where much of the whitefish and chub populations are found. The Michigan ban on gill nets will certainly affect these fishermen as well as those in Michigan.

In this regard, it is unfortunate that the gill net ban applies equally to all waters. Though trout do inhabit the northern waters of Green Bay, their populations are most abundant in the deeper parts of the main lake. Lake trout catch in Green Bay has historically been largely an incidental catch which increases when fishing pressure on whitefish increases.[73]

The chub stocks, which have been gradually reduced from a multi-species fishery to a single species fishery, are in poor condition and the Wisconsin DNR has closed the chub fishery indefinitely.[74]

Green Bay fishermen had a good harvest of whitefish in 1973, the total reaching 877,569 pounds, but in 1974 the catch had dropped to 475,017 pounds.[75]

Now another kind of problem is plaguing fishermen and complicating the picture. High levels of the pesticide DDT and other chlorinated hydrocarbons have been found in the flesh of Green Bay fish. PCBs (polychlorinated biphenyls) have also turned up in the fatty tissues of Lake Michigan fish. The Wisconsin DNR has warned citizens to limit their weekly consumption of these fish (see pp.p88-89 for further discussion).

6.5 SPORT FISHING ON GREEN BAY

> Although there are not statistics to show the amount of fish caught by sportsmen and other pleasure seekers [on Lake Michigan] ... it is, nevertheless known that the quantity and value of the fish so taken amount to a large aggregate .... the writer feels safe in estimating, from his own observation, that no less than $10,000 worth of fish are taken for each year from the breakwater at Chicago [in 1885][76].....

Like the other Lake Michigan waters, Green Bay's sport fishing history goes back almost as far as its commercial fishing history. Even in the 1880s the state fish wardens were well aware of "the large sum of money being brought into Wisconsin each year by the tourists who flock to our own summer resorts."[77] They were also aware that one of the prime attractions was the fine fish supply of lakes and rivers. It is clear that the tourist economy was a major impetus behind early game fish stocking programs.

In the late nineteenth century Green Bay was a popular recreation area. Part of its appeal was the boating and fishing available on the Fox River and in the bay.[78] There were northern pike to be speared; perch bass, walleye and catfish to be hooked; herring to be netted and, in later years, smelt to be dipped from the rivers on their spawning runs. In winter, sportsmen would venture further from shore, catching trout with hook and line under the ice.

But as the Fox Valley become more industrialized and urbanized, the water quality of the lower bay deteriorated and the area lost its country charm. Since them the main users of the bay have been mainly local people—and this trend will probably continue. The sportsman from urban centers such as Chicago or Milwaukee prefers to go inland and further north for his fishing, seeking a more rugged "north woods" atmosphere.[79] And those who want a "deep-sea trolling" experience seem to prefer Lake Michigan proper.

Of course, exceptions to this general trend have occurred. In those years and seasons when sport fishermen were especially well-rewarded for their fishing efforts on Green Bay, they have come from miles around. But generally, even for counties like Marinette which face on northern Green Bay, the recreation emphasis has been on the inland lakes. According to Ditton's recreation study, even local people now rely heavily on the inland lakes for their fishing activity.[80] Consequently, community concerns have focused on the quality of those lakes to the neglect of the bay.[81]

Recreational fishing on lower Green Bay is relatively poor today. Eutrophication and loss of habitat have made the lower bay the domain of the carp and bullhead. It is a sad commentary on the fishery that species described as rough fish in the 1880s[82]—pike and bass—would be a welcome addition to a Green Bay fisherman's creel today. Even if the lower bay's water quality should improve, it is likely that sport fishing there will remain a local affair. This belief is based on the fact that the lower bay is too warm and shallow to support the eagerly sought salmonid fish, and on the supposition that fish catch in the lower bay will always be limited to those species that can tolerate enriched waters. (It is reasonable to assume that eutrophication will persist in the lower bay in varying degrees as long as the Fox-Wolf River drainage basin remains a highly productive industrial and agricultural region.)

If Fox Valley sportsmen stayed home and fished their own backyard, there would undoubtedly be some dollar impact on the economy of the lower bay. More money would flow to sporting goods retailers and shorefront eating places. While increased fishing in the lower bay would probably have a relatively small positive effect locally,[83] it could have a larger negative effect on the recreation economy of the northern bay counties.

At the present time, the northern bay is a more popular sport fishing area and holds more promise for increased sport fishing in the future. Trout and salmon occur in the deeper, colder waters near the mouth of the bay and come up the rivers and streams on their presently fruitless spawning runs. However, the trout and salmon are neither as abundant in the bay as in the open lake[84] nor are they as readily accessible to the sportsman. Of the 98 Wisconsin charter boat operations that William Strang studied in the counties bordering the bay and the lakeshore, only two were located on the western and southern bayshores.[85]
of boats are located in Sturgeon Bay and Algoma, and they fish the main lake.

The lack of charter boat facilities in the northern bay and the severity of weather in this area, can keep most anglers, including small-boat owners, on shore for as much as half of the trout and salmon fishing season. For urban dwellers from Illinois and Wisconsin who want to charter fish, the Door, Manitowoc, Sheboygan and Kewaunee counties are more readily accessible than the northern bay ports,and they offer the chance to fish "the big lake." These are two attractions that northern Green Bay cannot offer (although in rough weather Green Bay can do a very good imitation of the "big lake.")

Expansion of sport fishing facilities (charter boats and docks) in Green Bay may be partly hampered by the small businessman's difficulties in acquiring capital—a continual problem in the northern counties. Nevertheless, the people are enterprising and have proven quick to take advantage of economic opportunities as they have arisen. Van Oosten described the brief but significant impact of the exploding smelt population on the Great Lakes economy:

> From the economic point of view the smelt grew to be an asset of no mean importance in many Great Lake communities. First came the smelt-dipping jamborees (during spawning runs up stream) and the nationally advertised carnivals or festivals which brought a tourist trade in early spring—normally a closed season in the resort centers. Then came the shanty ice-fishing and smelt villages or "smeltaniae" which drew thousands of anglers to the north. Later the commercial fishermen of Green Bay ... developed gear for the capture of the species under the ice in winter.[86]

A similar situation occurred in northern Green Bay in 1948 and 1949. In those years the walleye catch around Big and Little Bay de Noc was very high due to the exceptional survival of the 1943 year class. According to Pycha "...sport fishing pressure expanded rapidly and extensive resort facilities were built to accommodate the greatly increased numbers of anglers."[87] In fact, the fishing was so good that "many local anglers took out commercial licenses."[88] As the good fishing continued into the early 1950s, various tourist interests attempted to restrict commercial fishing in an effort to keep a good thing going. But since it was clear that the 1943 year class would soon be exhausted, restrictions were not adopted.

Whether opportunities for the recreation industry come on a grand scale, as they did during the walleye period, or whether they come in constant but small doses, the recreation business is vital to the upper Green Bay economy. The potential impact of sport fishing on a local economy is exemplified by Kapetsky and Ryckman's economic analysis of lake trout sport fishing in Grand Traverse Bay, Michigan.[89] The bay had 22 charter boats and 16 public boat launching sites in 1971. Between 1971 and 1972, direct community income attributable to the fishery was $136,000. With an income multiplier of 1.5, the total community income amounted to $204,000. Nonresidents accounted for 69% of the fishing activity and boat fishermen using public boat ramps contributed about half the revenue. According to the investigators, charter fishermen, although few in numbers, "provided 38% of the gross income from fishing by virtue of their large daily spending."[90]

Despite these substantial sums, recreation businesses such as resorts and boat rentals often bring only marginal monetary returns to their owners. For example, Strang found that the Wisconsin charter boat industry had an overall impact of $3,456,000 dollars on Wisconsin's lake Michigan communities in 1973, but provided only minimal income to the individual charter captains.[91] According to Strang, most captains derive only half of their yearly income from charter trips.[92] However, Strang also found that "most of the operators seem to have entered the industry in large part because of the psychic income...the opportunity to fish and spend time on Lake Michigan."[93]

Unfortunately the recreation economy often finds itself in conflict with equally important or more traditionally established sectors of the economy. In this regard, the recurring conflicts between sport and commercial fishermen that arise on Lake Michigan whenever the fishing is exceptionally good seem destined to continue. Even Illinois with its relatively small strip of lake front has recently found itself compelled to form a special council "to deal with the growing problems between commercial and sports fishermen on the waters of Lake Michigan."[94]

The antipathy of some of today's trout and salmon sport fishermen toward the so-called "killer nets" of the commercial whitefish fishermen is reminiscent of the strong feelings expressed against the commercial harvest of walleye during their 1948 population boom. In such conflicts, it is often the professional fisherman who loses out. Such a loss occurred in the 1930s when "deep-sea trolling" for lake trout was popular in Grand Traverse Bay, Michigan.

> ...[Commercial fishermen,] in an attempt to lessen friction between sport and commercial intersts, avoided the sport trolling grounds during the peak of the tourist season.... Consequently, [commercial] fishing intensity may have been lower then normally would be expected in some years when lake trout were relatively plentiful.[95]

Throughout the rural and sometimes impoverished areas of northern Lake Michigan, the continual search for economic opportunities tends to emphasize the quick returns of sports fishing and override the longer range need for a balanced fishery that provides both sport and food. Thus it is that "big game fishing" and its attendant conflicts are encouraged rather than discouraged in an area like Green Bay which has an established commercial whitefish industry and the potential for continued commercial fish production. Yet, there would be less need for bayshore areas to "supplement their incomes" with sport fisheries if commercial fishing were still strong—if fishermen had not consistently over-exploited fish stocks, moving from one lake to another, from one bay to another, harvesting as intensely as possible when the fish were available. There is obviously room on Green Bay for both commercial and sport fisheries. That both should be carefully and strictly regulated seems imperative.

6.6 REFERENCES (FISHERIES)

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7. FORESTRY

7.1 FOREST HISTORY

To the north and west of Green Bay City, the oaks and hickories begin to mingle with the pines, hemlocks, and maples characteristic of northern Wisconsin (See Figure 49). The virgin forest of this region was rich with straight, mature white pines. In some places the pine was interspersed with hardwoods and other conifers, but in other places the pine formed pure majestic stands.

The pine forests of the Green Bay watershed began providing lumber for the local trade as early as the 1830s. But it was not until the mid-1840s that lumbering became an important industry of the region. During those years lumber prices were high and eastern capital was seeking investment opportunities. The investment opportunities were found in the forests of northern Wisconsin.[1]

Lumbermen from Maine, New York and Pennsylvania sent their "land looks," as timber cruisers were then called, to scout the forests of the Lake States that the federal government was so anxious to sell. By 1860, Wisconsin's lumber boom was well on its way. The greatest activity centered on the Chippewa and Wisconsin Rivers, the Lake Superior region, and the Green Bay watershed.[2]

As timber cutting took on a larger scale, the water-driven sawmills, which were subject to the whims of river flow, were replaced by the steam mill. This innovation, in turn, accelerated the scramble for timber holdings. Eventually, some mills owned as much as 200,000 acres of forest, scattered through Wisconsin and Michigan.[3] These large holdings were meant to guarantee a long life to the sawmill.

Logging operations touched all of the counties within the Green Bay watershed. However, the most important areas were on the Wolf, Oconto, Peshtigo and Menominee Rivers.[4] Timber cutting began along the river banks and tributary streams.[5] Not only did some of the finest quality timber grow there, but the streams themselves provided cheap transport for bulky logs (See Figure 50).

Until the railroads reached the lumber regions in the late 1860's and early 1870's, the lumbermen relied entirely on water transport--water to carry the logs down river to the mill, water to drive the saws, and water to ship the cut lumber to finishing plants in the lakeshore cities such as Green Bay, Oshkosh (on Lake Winnebago) and Chicago.

Chicago--midway between the forests and the prairies--was in a unique geographical position. With its railroads, it formed a vital

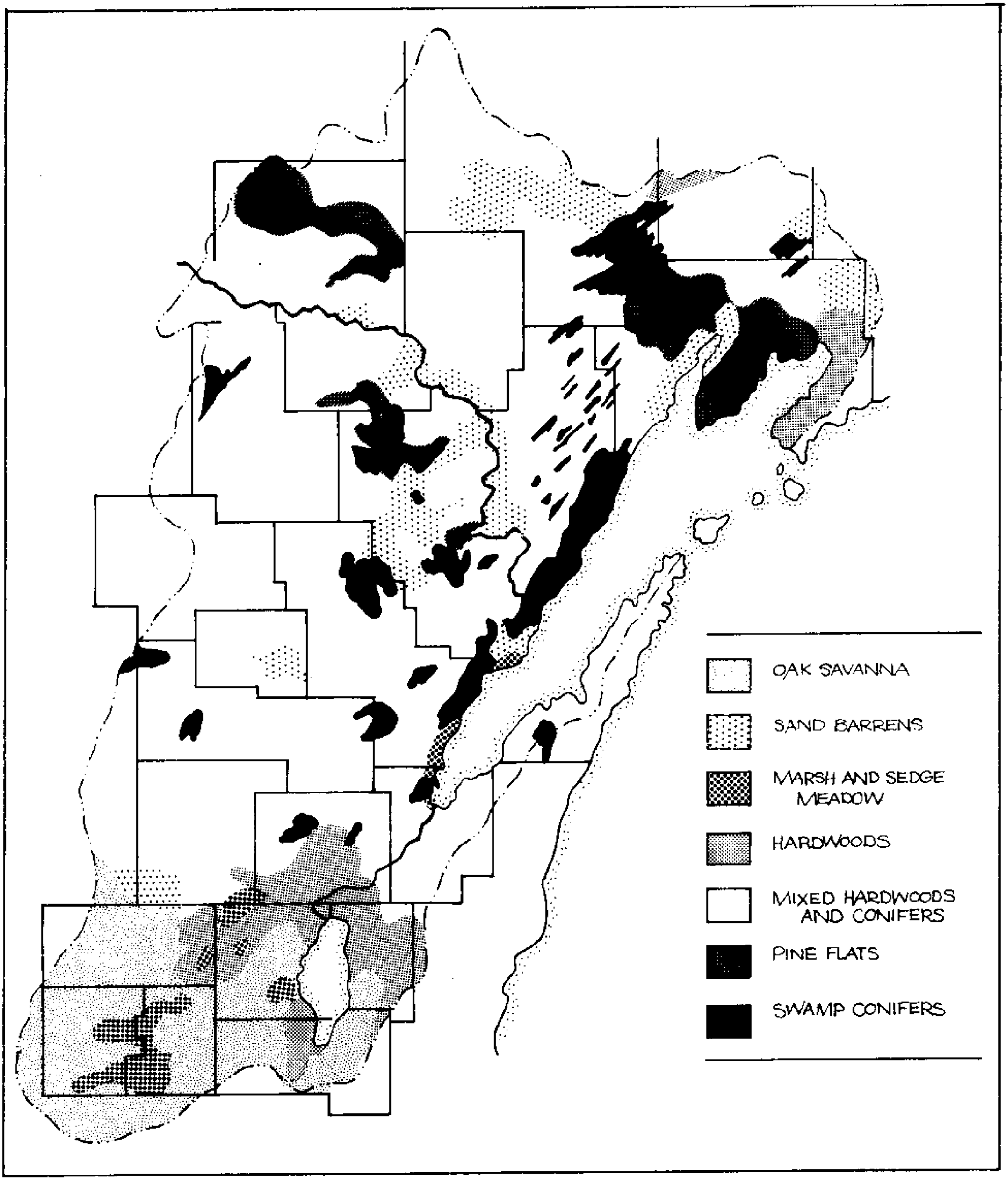


Figure 49. Original Vegetation of the Green Bay Watershed ca. 1850

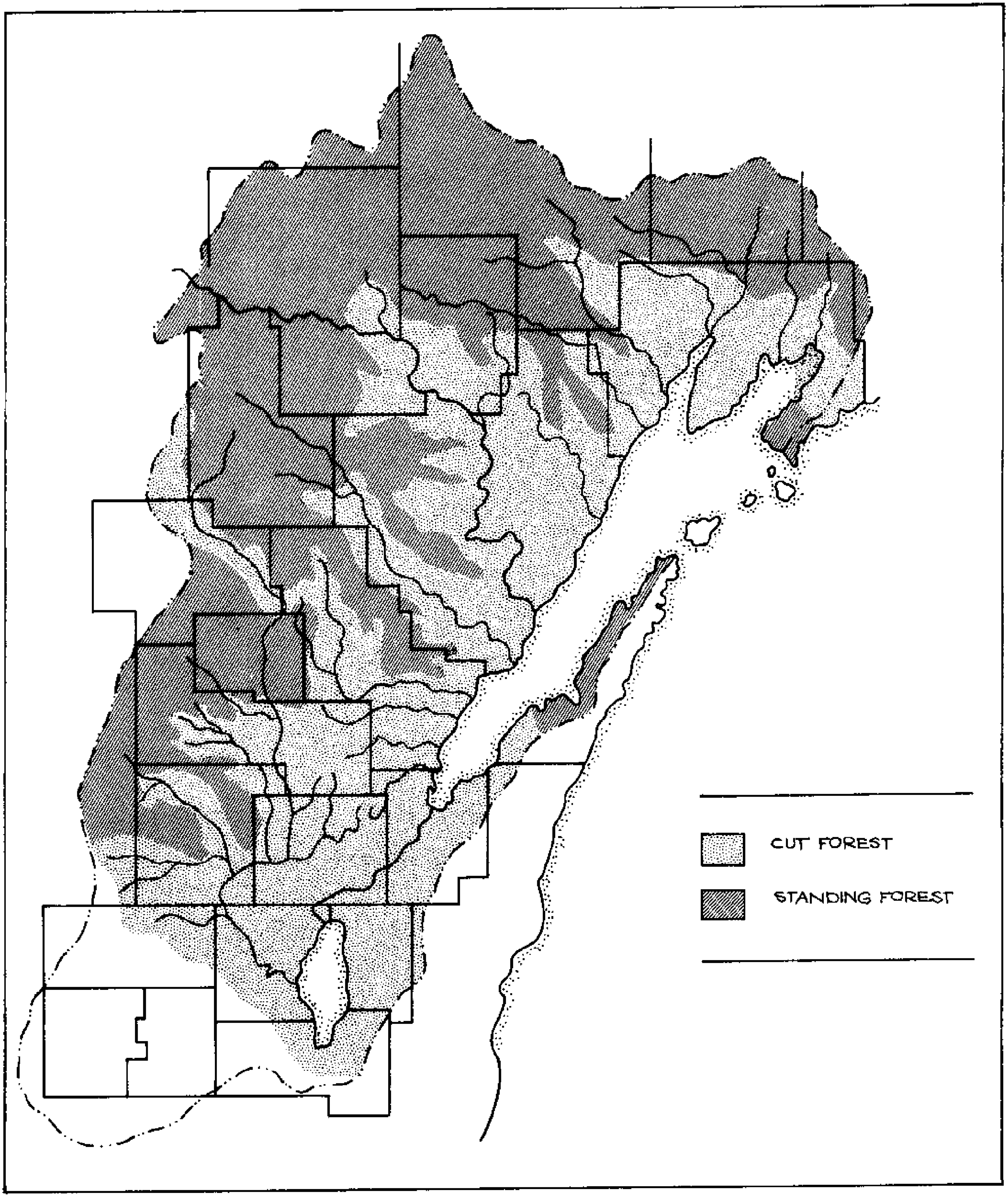


Figure 50. Harvest of Forests in the Green Bay Watershed, 1881. From C.S. Sargent, Report on the Forests of North America, Washington D.C., 1884.

lifeline of supply to settlers on the treeless prairies. Eventually, Chicago became the largest lumber distributing center in the world.[6] Many of the large lumber companies on Green Bay had mills in Chicago, while Green Bay City itself became the "lumber mart" of Wisconsin.[7]

To look at some Marinette and Oconto County streams today, it does not seem possible that they could have ever floated a log. But the lumbermen knew how to "improve" a stream so that it could carry hundreds of logs. "Improvements" consisted of removing snags, blasting out obstructing rocks and constructing a series of small dams.[8] The dams served two purposes: They flooded difficult areas of rapids and falls, and they stored up large volumes of water. This water formed a "head" which, when released in the dry season, could drive logs in one long rush down to the main river or pond. The Menominee River and its tributaries were at one time restrained by 41 dams, some over 800 feet long.[9] The Oconto and its sidestreams were once monitored by 18 different dams.

When a number of independent lumber companies were operating on the same river, conflicts often arose over who was going to drive his logs first and who was going to build the necessary dam. A solution to these problems was found in the boom company.[10] The company was paid by the local lumbermen to improve the streams, direct the log drive and sort the logs at the end of the drive.

The preparation for the log drive began in the deep of winter when the rivers were frozen and the snow was deep.[11] It was then that the axmen and sawyers felled their trees and banked them at the streamside. This work was done in winter for very practical reasons. During spring and summer the muddy ground and bushy undergrowth made it almost impossible to haul the big logs from the forest to the river's edge. But in winter the snow and ice could be packed to a smooth swift track. Then, oxen and horses easily could draw heavy sleds of logs to the river landing where they would remain until spring.

As ice covers broke up and melting spring snow swelled the streams, the winter's harvest of logs were sent down the tributaries to the main river.[12] There they remained until the boom company could build up a sufficient head of water for the main drive to the mills, often a distance of a hundred or more miles.

When the sluice gates were finally opened, rivers became alive with churning, tossing logs. Then the "river rats," armed with their peaveys, set to the dangerous task of log driving. These men were strong and tough, and the best of them formed the "jam crew" which followed the drive and broke up log jams where they occurred.

> Traditionally, the river pig dug his boot caulks into the topside of a log, and standing insolently erect, drifted downstream with the current.[13]

Yet, despite their daring agility, many drivers lost their lives each year on the rivers of logs.

After a drive of sometimes 100 or more days, the logs would arrive at their final destination. They would be collected at log ponds, where they were sorted according to the owner's log mark--a kind of brand -- measured (or "scaled"), and collected into a raft to be towed to the owner's mill.

By the late 1870's, the mouth of every log-producing river was lined with lumber and shingle mills. The Menominee went from 4 mills in 1867 to 20 mills in 1893.[14] In 1872, 24 mills lined the banks of the Wolf River at Oshkosh, or "Sawdust City" as it was then called.[15] In 1870, Brown County alone boasted 60 mills of various sorts.[16] And in Sturgeon Bay and other Door County harbors, cedar milling was the principal business.

While the northern bayside mills were turning out lumber, shingles and lath, the Wolf and Fox River Valleys were becoming increasingly important centers for the manufacture of finished wooden products.[17] The earliest mills had been at the foot of the Wolf River, and the towns of Oshkosh, Fond du Lac and Neenah-Menasha established strong traditions of manufacturing. From numerous planing mills came doors, sash, blinds, flooring and siding. Wooden sleighs and carriages were manufactured, as well as basswood barrels for shipping glucose, pine barrels for salted fish, and white oak tubs for butter.

The valley industries made heavy demands on nearby forests as well as on more distant ones. Maple, for example, was heavily used as a fuel, especially in the form of charcoal. It was among the woods burned by the Fox River Iron Foundry in DePere. This foundry used more than one and a half acres of timber land per day per furnace. It was claimed in 1881:

> This rapid consumption of timber has so reduced the area of available woodlands. . . that the charcoal supply (is) now drawn from kilns located along the lines of the Chicago & Northwestern and the Green Bay, Winona and St. Paul Railway, at a distance of from 20 to 80 miles from the furnaces.[18]

The pineries, too, dwindled rapidly under intensive cutting. Their production peaked around 1889-1890 (Table 37). Thereafter, both volume of wood and the size of the pine logs declined (Figure 51).

Table 37. Million Feet of Forest Product Harvested on the Menominee River*

1867	60
1872	142
1883	422
1889	642
1892	560
1895	267

*Derived from F.C. Burke, Logs on the Menominee, (1946), pp. 54, 70.

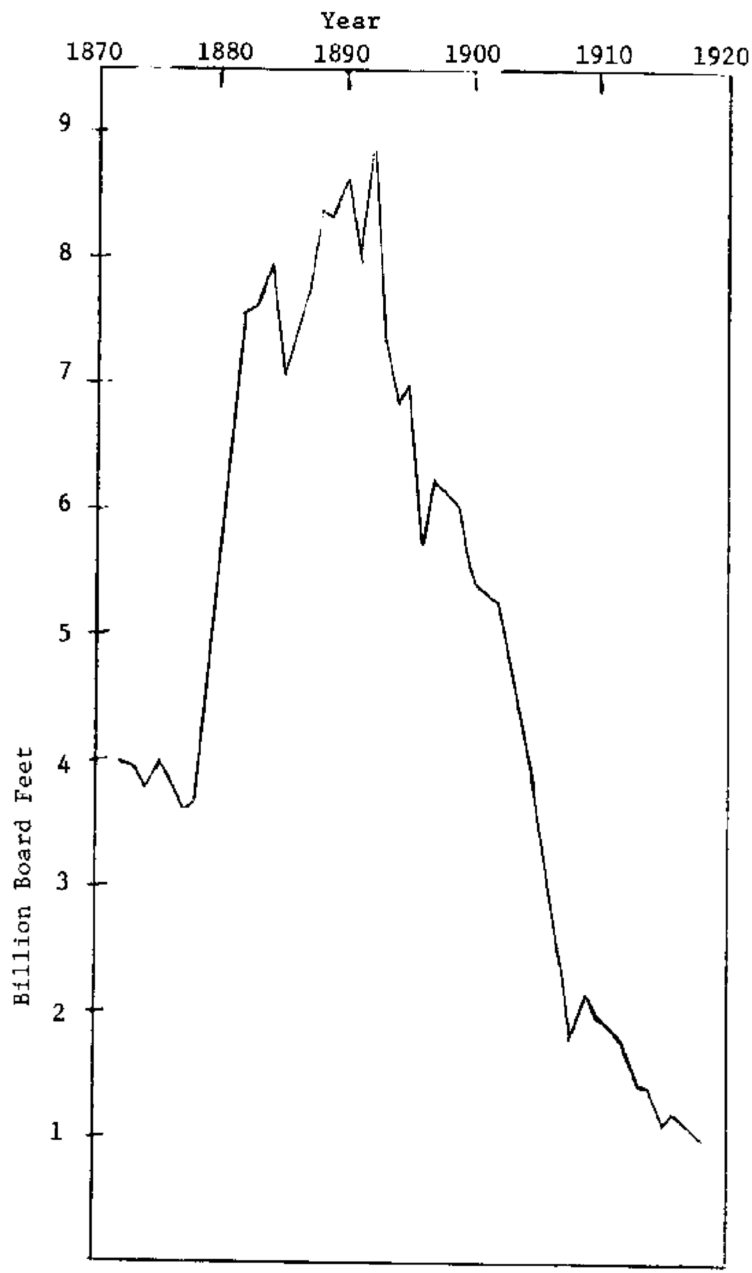
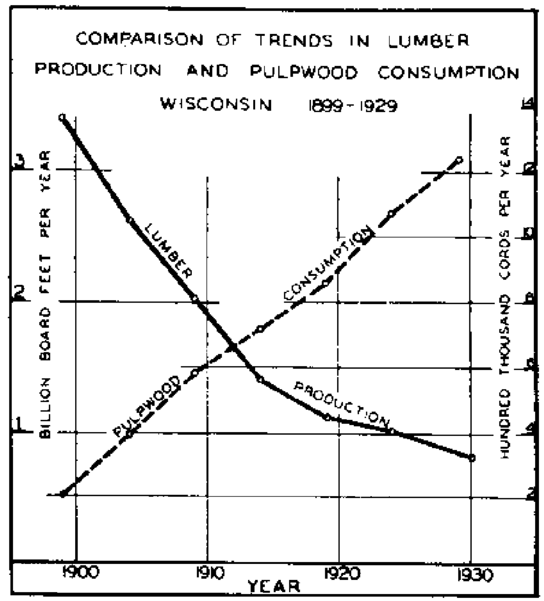


Figure 51. Pine Lumber Production in the Lake States, 1873-1918.

From W.G. Rector, Log Transportation in the Lake States Lumber Industry, 1840-1918. (1953).

Figure 52. Trends in Wisconsin Lumber Production and Pulpwood Consumption, 1899-1929.

From Forest Land Use, Madison, Wisconsin (1932).



By 1889, many mills had begun turning to hemlock to supplement their production of lumber and to supply bark to the leather tanneries. They also began processing cedar, fir, and spruce logs and some hardwoods.[19]

7.2 NEW SPECIES AND NEW METHODS

As hemlock and hardwoods made up more and more of the harvest, river drives became impractical.[20] Hemlock logs rode low in the water and hardwood would not float at all. The answer was the narrow gauge railroad, an innovation which became commonplace in the lumber camps by the late 1890's. Financing a railroad was an expensive proposition, and a great deal of consolidation of smaller mills occurred at that time. The emphasis was on bigness and on high production rates.[21]

> When the land was stripped of its most valuable resource, the engines were moved, the rails picked up and the entire road was often transplanted to another area. In twenty operating years, one lumber company laid and picked up about 2,500 miles of trackage. . . .[22]

Steam power also took a bigger role in water transport. In the 1870's the first steam barges, forerunners of the lake freighters, began to appear on the Bay.[23] Their dependability and ability to maneuver in narrow places made them strong competitors for the monopoly on bulk cargo transport which schooners had held until then. Even the fastest schooner was limited by its dependence on wind.

> At times after several days of brisk north winds, which aided the ships coming down from Wisconsin, the Chicago River was crammed with lumber cargoes from the Lake St. Bridge down to the Clark St. Bridge. At such times bidding and buying were very active. On the contrary, after a long period of south wind, the river would be nearly empty. The Wisconsin and Upper Michigan men had to depend on the wind to sail their cargoes down from the loading points. Lower Michigan men had an advantage. Their shipments came in quite regularly because they used steam barges to transport the lumber across Lake Michigan.[24]

Freight schooners, like the log drive, continued to be a part of the lumber scene until World War I. But their role was a rapidly diminishing one. In 1880, the port of Green Bay reported the arrival of 270 steamers and only 97 sailing vessels.[25]

As pine production went into decline, many mills and factories shut down. Those that survived did so by being flexible--by converting their sawmills into planing mills or furniture factories that could make use of the increasing cut of hardwood. Of course, some businesses were not only flexible, but far-sighted as well. The Menasha Wooden Ware Company, for example, early purchased large tracts of virgin timberlands in Wisconsin, northern Michigan, Minnesota, Idaho, Washington, Oregon, New Mexico and Canada.

> In 1921, foreseeing the great increase that was due in the dairy business, the company took on the manufacture of butter tubs made from Sitka spruce.[26]

The spruce was from the company's own lands in Oregon. By 1927, the company had begun making paper cartons.

But for those who preferred the saw and axe, there were the pine forests of Louisiana and the Pacific Northwest.[27] Many northwoods lumber operators simply sold their Wisconsin and Michigan lands and dams to the increasingly numerous papermills and headed for the waiting virgin forests in other corners of the nation.

Those that remained in the local logging business in post-World War I years found themselves running a different kind of operation. For, by 1920, the logging truck had begun to replace the railroad as the prime means of lumber transport.

> Many small patches of pine that formerly had been too far from a driving stream and too small to warrant the building of a logging railroad fell before the flexibility of truck transportation and the mobility of the portable sawmill.[28]

The Wisconsin lumber industry was entering a new era--the era of the pulpwood log of spruce, fir, and later, aspen.[29] It was also returning to an era of the small lumber operation.

These changes were hastened along by passage of the Forest Crop Law in 1927.[30] Prior to the new law, forest land owners had been taxed on the value of the standing timber. The longer the trees stood, the heavier the tax became. The lumbermen had to "cut clean and get out" in order to make a good profit. This was especially true in the later stages of the lumber boom when heavy capital investments in railroads and high stumpage prices inclined the lumberman to take out everything that would give him a return.[31]

But after the lumbermen "got out," the lands generally became tax delinquent and, at least fiscally, were totally unproductive. Both Michigan and Wisconsin responded to this situation with laws that removed forest lands from the assessment rolls and deferred the tax until the forest crop had matured and could be harvested. In Wisconsin, these lands became county forests; in Michigan they became state forests.[32]

The law also gave private forest owners a new tax system. As originally set up, the law required the forest owner to pay the state a 10¢/acre/year tax until the timber was cut. Then he paid 10 percent of the value of the harvested crop in tax. This system enabled forest owners to practice selective cutting without taking a profit loss.

7.3 THE FOREST INDUSTRY TODAY

By the post-war years, the northern forest had changed and the pulp log was growing in importance (See Figures 52 and 53). However, in 1930, the pulping processes were specific to spruce, fir and hemlock, and aspen comprised only 4 percent of the pulpwood cut.[33] But in 1932, the Wisconsin Committee on Land Use and Forestry stated:

> Pulp research . . . indicates that aspen is suitable for sulphite pulp. Few pulp men believe that any of these substitute woods will completely replace spruce, which is the wood "par excellence" for all the finer grades of paper, but if even a small fraction of the available supplies of aspen can be utilized, it will be a big help in the maintenance of the Wisconsin industries. Probably an equilibrium will be reached by adapting mills to a greater use of such woods as aspen and jack pine and by the development of a larger supply of local spruce.[34]

It was not until the 1950's that aspen really became an important pulp species. Aspen now comprises at least 50 percent of the pulpwood cut and makes up almost half of all species cut in the Lake States (Figure 54). It is estimated that within 30 years, aspen will be harvested to the hilt of its allowable cut.[35]

The fast-growing aspen forest which moved in on slashed pine lands and abandoned farms is now approaching maturity. Large areas of mature aspen on better soils are being replaced by northern hardwoods through natural succession.[36] This means that pulpwood foresters must either maintain their aspen forests artificially through site treatment, or the papermills must adapt to handling increasing amounts of hardwood pulp.[37] Since many papermills are almost completely geared to aspen pulp and have invested money into aspen breeding programs, site management is the more likely choice to be made.

There is some tendency now to use the larger size aspen logs for purposes other than pulping. Aspen's smooth, almost grainless wood is similar to basswood and is ideal for veneer work, cabinetry and furniture.[38] It is also a good wood for crates and boxes and is being used increasingly for excelsior and particle board. The success of these trends away from aspen's major use as pulp depends largely on the creation of a "new image" for the "popple." If the new image catches on, pulp mills may find themselves using fewer big logs and more residues from aspen manufacturing plants. The Forest Products Laboratory in Madison has undertaken studies (Project STRETCH) which show that:

> . . . approximately 4 billion board feet [of all U.S. timber] can be saved annually by greater utilization at the logging site and in the sawmill, by veneer and particle board processes and by more efficient building. . . . There is a further potential saving of 6 to 8 billion board feet by diverting saw logs now used for pulp. Pulpmills could use other wood wastes or chips from smaller logs. . . .[39]

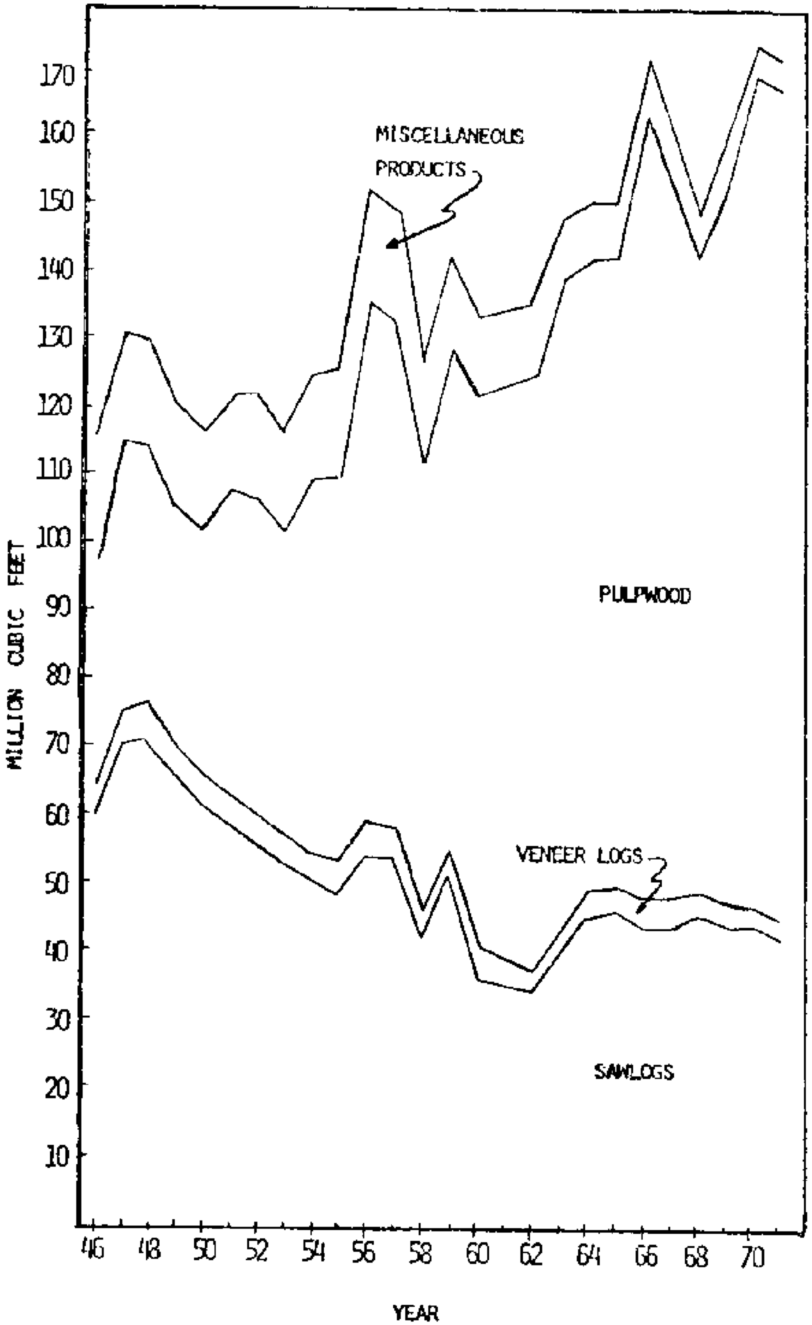
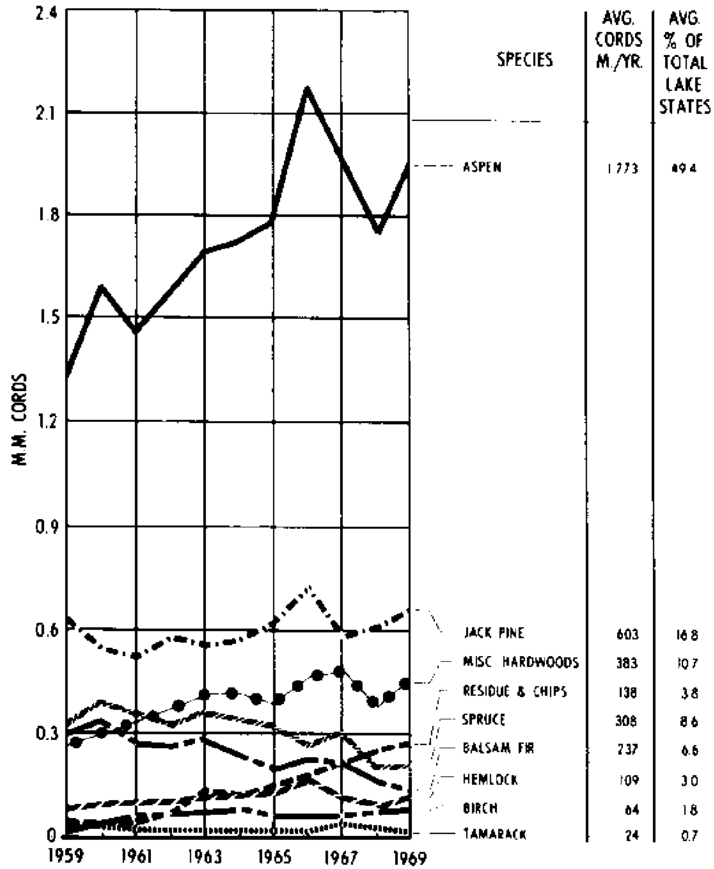


Figure 53. Wisconsin Timber Harvest By Product (Excluding Fuelwood), 1946-1972.
From U.S. Forest Service, North Central Experiment Station.

Figure 54. Lake States Pulpwood Production By Species, 1959-1969.
From Aspen, Symposium Proceedings, North Central Experiment Station, U.S. Forest Service, 1972



Until such time as the pulp industry converts to use of smaller pieces of log and branch, there will be intense competition for every cord of aspen. This is because for the first time in modern times there is a shortage of various paper products. The shortage is expected to continue for at least several more years. There are speculations that the rising price of paper will make papermill expansion economically feasible for the first time in many years (see discussion pp.198-199). This means not only the creation of new mills but an increased demand for the pulp materials that keep the mills going.

In Wisconsin, the northeastern counties are the prime producers of pulpwood (Figure 55). In Marinette and Oconto Counties and in the counties on the northern reaches of the Wolf and Menominee Rivers, much of the forest land is under government management--mainly federal and county.

The Nicolet National Forest holds extensive areas, especially in the inland counties. According to the current Nicolet Timber Management Plan, 89,700 acres will be selectively cut over a 10-year period. Over the same period, 52,000 acres will be clearcut. The clearcutting is mainly aimed at regenerating aspen which now comprises roughly 40 percent of the forest vegetation.[40] In general, the national forests in all the Lake States are now using almost all of their allowable clearcut acreage. The Forest Service follows three management options on timberlands in this region: clearcut on a 45-year rotation for aspen; encourage natural conversion of aspen to hardwood on better sites; reforestation of maturing aspen stands with softwoods.[41] According to the Forest Supervisor on the Nicolet National Forest, there are no limits on clearcut size, but cutting area is influenced by aesthetic and wildlife management concerns.[42] Cutting is restricted along streambanks, and there are not currently any significant erosion problems.

Of the Wisconsin bayshore counties, Marinette and Oconto have the largest areas of county forest, with Marinette far in the lead (Table 38). However, only a small parcel of county forest (Oconto County) occupies a bayshore site in Wisconsin. In contrast, large areas of bayshore on the Upper Peninsula are in public forest. Arlan Wooden, Marinette County Forester, says that most of that county's forest is on reclaimed tax-delinquent farmland. The lands are managed primarily for aspen now.

In Marinette County, timber sales are contracted at auction by sealed bid. The designated aspen acreage is clearcut and its harvest generally amounts to 20,000 to 25,000 cords/year. Of the year's sales, 20 percent goes to the state, 10 percent to the towns, and 70 percent stays with the county. The Marinette County forest runs in the black with a $300,000/year income to the county.[43] There are approximately 160 loggers in the county, many of them on three- or four-man crews. These small jobbers generally have to sell their logs through larger operators who have contracts for 2,000 to 3,000 cords. With current high pulpwood prices, the loggers work year round.

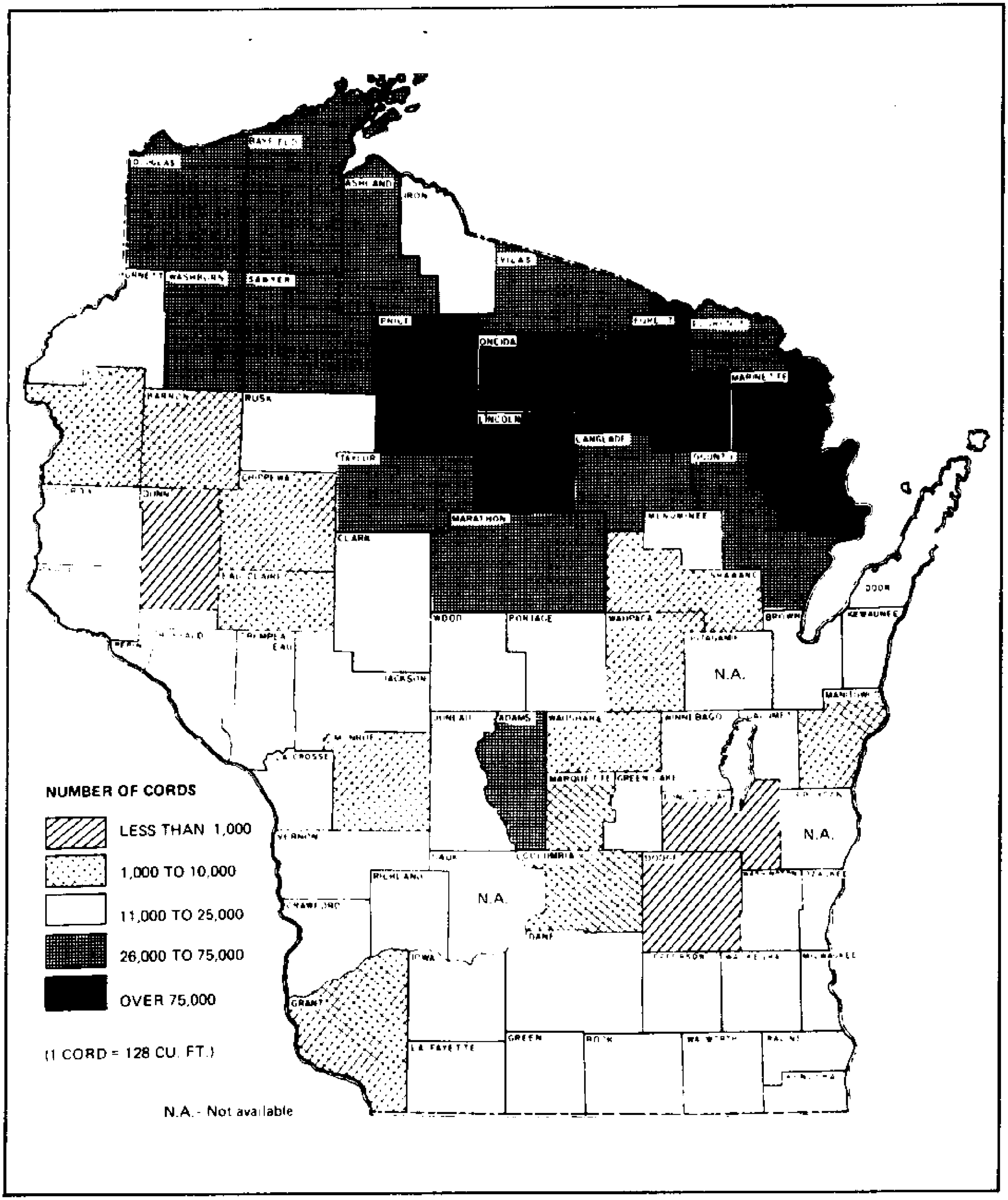


Figure 55. Pulpwood Production By County, 1969 (Rough Wood Basis).
From U.S. Forest Service, North Central Forest Experiment Station.

Table 38

Areas of Forest Land by Ownership in Wisconsin Counties Bordering Green Bay (1968)

Thousands of Acres

County Name	Brown	Door	Marinette	Oconto	Shawano*
Commercial Forest Land	36.9	96.2	649.9	357.7	485.4
As % of Total Forest Land Area	11.0	33.0	77.0	57.0	61.0
National Forest	0.0	0.0	0.0	127.4	0.0
State Forest	0.3	1.4	10.5	2.9	2.4
County and Municipal Forest	1.6	0.3	229.8	43.8	1.0
Forest and Industry	0.2	1.4	37.6	5.5	234.9
Farm	24.7	60.9	85.7	78.4	113.0

* An inland county

From Tables 1 and 2 of Wisconsin Forest Resource Statistics, Lake Michigan Survey Report, Wisconsin Department of Natural Resources, 1969.

Pulpwood production is also a major industry of the Upper Peninsula counties of the watershed, especially Menominee, Delta, Iron and Marquette Counties. As of 1969, these counties each produced approximately 90,000 cords of pulpwood.[44] Almost all the forest area and a major portion of each county is under state management, having been acquired as tax-delinquent lands through the Pearson Act. Sizable acreage also occurs in the Hiawatha National Forest, which includes about two-thirds of Delta County.

While the pulpwood industry has been picking up since the 1950s, woodenware and lumber products industries have gone through some hard times. A large hardwood flooring and birdseye maple furniture industry which had sprung up in Escanaba and Menominee between 1890 and 1920 began to taper off around 1950.[45] The same was true for the great wood product centers of Oshkosh and Fond du Lac in Wisconsin. With the craftsmanship of woodworking entrenched in these communities, they had successfully imported woods from the west and south and Canada as local supplies of pine and then hardwoods dwindled. But as light metals and plastics began to compete with wood, the industry began to suffer.[46] Other factors contributed too: competition from foreign and other domestic manufacturing areas and a decline in hardwood supplies, especially quality birch, maple, and oak. Many of the needed woods are not produced commercially on any scale in the region and must be imported from Canada.

However, the demand for wooden products continues. Hardwood moulding has come back into fashion in new homes (for those who can afford it), and the preferred kitchen cabinet is again the wooden one. The rising prices on hardwoods have led some private forest owners astray, and clearcutting has occasionally been a serious problem in a few hardwood areas.[47] Since hardwoods require a moderately shaded site for successful reproduction, a clearcut sets back the forest's development by many years and encourages low quality growth. The DNR attempts to discourage clearcutting and to encourage private operators to settle for the longer term profits of selective cutting.

Although production of construction lumber has steadily declined in Wisconsin since World War II, a number of sawmill operations has perserved (Table 39). The largest mills are in Vilas, Forest, Marinette, Menominee and Shawano counties (all within the Green Bay drainage basin, except Vilas). More than 85 percent of their product is hardwood, mainly oak, maple, aspen and elm. It has been predicted that there will be a 29 percent rise in national lumber consumption between 1970 and 1980, assuming that the price of lumber does not rise faster than that of competing materials.[48]

An optimistic projection for Wisconsin production of construction grade lumber is that it will parallel national growth trends. This would mean a growth rate of less than one percent a year over the period to 1980 if lumber prices continue to rise. The projection is optimistic in light of the long term decline in Wisconsin production and the lack of any substantial comparative advantage for Wisconsin producers relative to the major supplying regions of the western and southern U.S. and western Canada. The outlook for lumber production for use in shipping is somewhat better based on prospects for pallet consumption and may represent the major opportunity for new development in the lumber industry in the state.[49]

Northeastern Wisconsin's sawtimber production is expected to concentrate on pallets from hardwoods and building studs from both hard and soft timber.[50]

Table 39. Number of Sawmills in Northeastern Wisconsin Counties (1967)

	Counties					
Size of Mill	Brown	Door	Florence	Marinette	Shawano*	Oconto
<1,000,000 bd. ft.		10	8	19	26	24
1,000,000 to 4,999,000 bd. ft.	2		2	1	2	5
5,000,000 plus bd. ft.				1	2	2

*Includes Menominee County

From Wisconsin Forest Resource Statistics, Lake Michigan Survey Report, Wisconsin Department of Natural Resources, 1969.

According to Michael G. Amrhein of the DNR Forest Tax Unit, the number of private holdings being managed for timber is decreasing. A comparison of plat maps over the last 10 to 15 years will show that private holdings of both forest and farmland in the northern counties are being divided into many small parcels. A study by the Wisconsin Department of Administration claims that almost 60 percent of commercial forest land in Wisconsin is in private hands.[51] Most of these holdings consist of less than 100 acres each, often too small a piece to be economically harvested. Many of them are recreational or summer home properties of nonresidents. As a result, they are largely "unmanaged" — neither harvested nor reforested. This means that those forests that are intended for harvest must be managed more intensively to compensate.[52]

According to the Department of Administration study, more intensive management generally involves "more frequent disturbance of forest stands, regulation of stand density, and control of species composition. These operations alter natural patterns of development and may lead to stands of lower aesthetic value."[53]

While national, state and county lands in Wisconsin account for 20 percent of the total state harvest[54] and could be forced to produce more, the result could be loss in sectors of the economy that depend on the forests for their recreation assets. Clearly, intensive management and extensive harvest have the potential to conflict with the recreation economy. Large timber cuts are aesthetically unpleasing to vacationers. Other management measures discourage desirable wildlife. However, there are a number of ways of softening these impacts. That such measures should be employed in areas of the public forest seems essential in counties that rely heavily on the tourist dollar.

7.4 FORESTRY'S ENVIRONMENTAL IMPACTS

The impacts of past forest cutting on Green Bay are difficult to know for certain. In the early days, there were no environmentalists to measure the changes. But from descriptions of the early lumber and milling operations, we can conclude that it was considerable.

The lumbermen left behind them acres of stumps and slash. An observer said of northern Wisconsin in 1898:

> ...about 3 million acres are without any forest cover whatever and several million more are but partly covered by the dead and dying remnants of the former forest...[55]

In the dry weather fires swept these "stump prairies" and travelers of the time commented on the smokey skies that often hung over the forest and bay. It was claimed that more than half of the areas of cut pine forest were burned over sooner or later, some more than once.[56] The heavy cutting and repeated fires had dramatic effects on the vegetation. Most of the mature cone-bearing pines which would have served to reseed the barren, fire-scorched ground were gone. As a consequence, rather than pine regeneration, there sprang up a vast crop of briers, pin cherry, aspen and white birch.[57] Later, hardwood trees grew up and some pine eventually reappeared.

Where there was a slope, erosion tended to follow each fire. Some of the heavy sediments were probably trapped behind the numerous dams, but much of it undoubtedly swept into the bay. Besides sediment run-off, the large-scale loss of forest cover was also followed by increased evaporation of water from the soil. The result was a decline in the natural recharge of the ground water table. In 1867, Increase Lapham described the drying up of springs after forest cutting:

> Such has been the change in the flow of the Milwaukee River, even while the area from which it receives its supply is but partially cleared, that the proprietors of most of the mills and factories have found it necessary to resort to the use of steam, at a largely increased yearly cost, to supply the deficiency of water power in dry seasons of the year.[58]

Other millers, like one in Fond du Lac, had to finally move their operations to other streams.

It is likely that as a result of low spring water flow and high nutrient run-off into streams, stream temperatures rose slightly and eutrophication occurred, at least locally, for varying periods of time.

This change alone probably did not have permanent impact on most aquatic fauna. But other factors may have had longer-lasting effects. For instance, the presence of numerous dams on the watershed's rivers could not help but obstruct some movement of fish to spawning areas.[59] The whitefish which was being heavily exploited at the time was known to spawn in riverbeds as well as on the shoals of the bay.[60] The loss of these spawning areas certainly added to the pressures building on the fishery.

Restricted fish movement up the rivers and streams undoubtedly affected other fauna dependent on the fish for food or other purposes. For example, the larvae of river bottom mussels and clams must go through a short parasitic phase in the body of a fish before they take up their sedentary bottom life. The absence of the appropriate host fish can mean death for the young mussel.[61]

The sawmills buzzed day and night and also worked their share of damage on the bay. Mill refuse was dumped in the most convenient recepticle—the river itself. Sawdust and wood chips floated out to the bay to either sink or wash onto beaches and into marshes. Bottom fauna was smothered and fish spawning grounds were blanketed.[58] Sawdust and mill chips were also considered cheap fill material for those who wished to build out into the bay, and the Peshtigo Lumber Company at the mouth of the river was built on an island of mill refuse.

However, since the decline of big lumber operations and the development of county forests with regular management, the impacts of lumbering on the bay have been minimal.

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8. PULP AND PAPER MILLS

8.1 EARLY HISTORY

Although paper manufacture today is based almost entirely on wood pulps, the basic materials of papermaking in 1840 were rags and straw. And these were the raw materials of the first paper mills in the Green Bay region. Contrary to common belief, the paper industry was initially drawn to the Fox River Valley not for its wood resource, but for its water power and its proximity to growing population centers.[1] (However, it was only a matter of a few years before the region's abundance of pulpwoods was making the lake states a paper manufacturing center.)

Because the Fox draws upon a vast drainage basin and is fed by many small streams, it has a strong, constant reliable current. Lake Winnebago acts as a midway holding pond, giving the Lower Fox River a uniformity of flowage that was highly valued by the early industrialists who sought a stream for power, processing water, waste disposal and transport.[2] The river flow was further refined by a series of dams and locks.

The first mills in the valley served the local printing trade and supplied an immediate market. The owners were mostly local businessmen, several of whom had operated flour mills on the Fox when wheat was king in Wisconsin.[3] Between 1860 and 1890 however, the paper industry underwent major changes. First came the mechanical pulping of wood (about 1840, and then the sulphite pulping process, 1866). These advances pushed wood to the front as the prime raw material of paper. The sulphite process was quickly adopted in the U.S. and the 1870s saw numerous wood pulp mills springing up along the banks of the Fox. The essentials were all at hand — extensive stands of spruce, hemlock and fir; water; and an expanding market.[4] By 1899 wood pulp made up about 52% of the materials used in paper in the U.S.,[5] and Wisconsin, with its wood pulp mills, was becoming an important wrapping paper producing state.[6] Simultaneously the railroads underwent rapid expansion (see Table 40), opening up large new markets to what had once been a local industry.[7]

Up through the late 1890s, water power was the major industrial power source (see Table 41). But by the turn of the century, many factories had begun converting to steam. Nevertheless, a good waterfront site was still essential for industrial processing waters, sewage disposal and transport. Other changes had also occurred by the 1900s. The kraft or sulphate pulping process had arrived in the U.S. in 1909 making possible the manufacture of wrapping papers and paperboard from the resinous pines of the South.[8]

The paperboard industry also got a boost in 1906 when the railroads finally approved the use of corrugated boxes for shipping freight.[9] Yet even after its acceptance for freight use, the corrugated carton was penalized or taxed by some railroads that had a strong tie to western lumber interests. When this discriminatory practice was taken to the courts in 1914, the paper box held its own and came out of the fray with freight rights equal to the wooden box. The immediate result of this decision was a phenomenal growth in corrugated mills whose numbers across the nation almost doubled over the following year.[10]

TABLE 40

RATE OF RAILROAD GROWTH IN WISCONSIN

Year	Miles of Track
1860	891
1867	1,030
1890	5,583
1910	6,533

From: The Paper Industry in the Lake States Region, 1834-1947, M. L. Branch, Ph.D. thesis, 1954, University of Wisconsin, p. 27.

TABLE 41

SOURCES OF POWER IN MANUFACTURING INDUSTRIES IN 1890

	All U.S. Manufacturing Industries	U.S. Paper Industry	Lake States Paper Industry
Water Power	22 %	69 %	81 %
Steam	78 %	31 %	19 %

From: M. L. Branch, thesis, p. 24

The years preceding and during World War I were boom years for the Wisconsin paper industry as demand for paper products grew by leaps and bounds. This increase was due largely to a growing national population, a rising literary rate, the stimulation of interest in current events by the war, and the need of a prospering industrial economy for a widespread advertising medium such as the daily paper.[11]

However, following the Great War, growth in the Lake States paper and pulp mills slackened as competition within the various paper product markets became intense.[12] Wisconsin by this time had depleted the bulk of its spruce and fir pulp trees and pulp logs of any species were becoming more expensive. Since "wood costs ... were the principle determinants of regional advantage,"[13] Wisconsin was clearly at a competitive disadvantage.

Meanwhile, with the aid of the relatively new kraft process, those mills close to the pine forests of the South and the Douglas fir and western hemlock forests of the Pacific Northwest had access to abundant cheap wood. It was Canada, however, with its vast boreal forests of spruce that had the greatest advantage. Aided by the Underwood Tariff of 1913 which had removed duties from imported newsprint, Canada gradually took over the North American newsprint market.[14] Domestic production everywhere took a dive, and newsprint making was essentially eliminated from the Lake States by 1919.[15]

8.2 A CHANGING INDUSTRY

The "packaging revolution" of the late 1930s gave rise to the tremendous expansion of paperboard manufacture in the South. However, Wisconsin continued to lead in wrapping paper manufacture and held its own in the paperboard market into the 1940s.[16] But between 1919 and 1949 Wisconsin paper firms began shifting their production away from these products and into the manufacture of higher value papers.[17] When mills such as those in the Fox Valley became dependent on imported pulp logs, there was little alternative but "...to make an insufficient supply of spruce and other scarce pulpwood go a long way by concentrating production on the more highly processed (and, incidentally, tariff protected) grades of pulp and paper. These embody more labor relatively to the cost of raw materials and are, therefore, more profitable to produce."[18]

Thus the Fox Valley and other Green Bay region mills turned their efforts to printing and writing papers, sanitary papers including tissue and toweling, and other specialty papers.[19] These are still the major products today (see Table 42).

Many paper mills of the Green Bay region rely heavily on imports of both pulp and pulpwood from Canada and other Lake States. Of the 19 mills on the Fox in 1972, 14 bought processed pulp from other mills, generally Canadian. Of these, seven mills used only purchased pulp. Four mills produced deinked pulp from recycled paper.[20] It should be noted that the importation of pulpwood from Canada has been declining rapidly and is predicted to drop to only about 20,000 cords by 1978. A certain amount of pulpwood, roundwood and residues, is imported from Colorado, Montana and other states in that area.[21]

TABLE 42. INDUSTRIAL WASTE LOADINGS

("A Guide to Water and Related Land Use in the Lower Fox River Watershed," E.F. Joeres, Yoram J. Litwin and J.T. Quigley. Special Report #503, UW Sea Grant College Program)

Industry	Miles above Mouth	Total Production tons/day			Manufacturing Process		
		Paper	Board	Pulp	Production Process	Product	Fraction of Production%
Kimberly-Clark Neenah Division	38.4	50	-	9	VII 2	Bond	100
Kimberly-Clark Badger Globe	38.2	65	-	-	VII 4	Tissue & towels	100
Bergstrom Paper Company	38.1	300	-	300	V VII 3	Book & Bond	50 50
Gilbert Paper Company	38.0	80	-	-	VII 2	Bond	100
John Strange Paper Company	37.9	-	300	300	VI	Paperboard	100
Kimberly-Clark Lakeview	37.5	230	-	-	VII 4	Tissue & towels	100
George A. Whiting Company	37.1	20	-	-	VII 2	Bond	100
Wisconsin Tissue Mills	36.9	85	-	60	V VII 4*	Tissue	100
Riverside Paper Company	31.4	90	-	90	V	Bond	100
Consolidated Paper Interlake Div.	30.6	-	-	155	II	Pulp	100
Kimberly-Clark Kimberly	27.3	530	-	45	IV VII 3	Book & Publication	15 85
Appleton Paper Inc.	25.6	480	-	240	IV VII 3	Publication	40 60
Thilmany Paper Company	23.2	515	-	390	I VII 5	Specialty	75 25
Nicolet Paper Company	7.3	118	-	-	VII_x	Dense Papers	100
U.S. Paper Mills	6.9	-	47	47	VI	Paperboard	100
Fort Howard Paper Company	3.6	850	-	724	V VII 4	Tissue & towels	85 15
American Can Company	1.0	450	-	220	II VII 4	Tissue & towels	50 50
Charmin Paper Company	1.0	997	-	526	II VII 4	Tissue & towels	50 50
Green Bay Packaging	0.7	-	285	215	III	Corregating Medium	100

PRODUCTION PROCESS CODE

I. Kraft Pulping and the Manufacturer of:
   1. Coarse Paper and Liner Board
   2. Newspring
   3. Bleached and Unbleached Grades
   4. Bleached Grades

II. Sulfite Pulping and the Manufacture of:
   1. Paper
   2. Dissolving Pulp

III. Neutral Sulfite Semi-Chemical
   1. Bleached (Chemi-groundwood

Treatment Facilities				Total Effluent		
Primary		Secondary		Flow	BOD_5	SS
1972	Future	1972	Future	MGD	lb/day	lb/day
-	M	-	M	0.7	43	113
-	M	-	M	0.5	153	346
CL-DF	CL-DF	-	M	5.0	21580	11362
-	M	-	M	0.7	5	2250
-	M	-	M	1.4	960	3056
CL	CL	-	-	4.9	499	246
CL	CL	-	-	0.15	200	
M	M	M	M	-	-	-
-	M	-	M	0.35		
-	M	-	M	5.3	17840	13300
CL	CL-C	-	-	11.0	18459	48170
-	CL-DF	-	-	5.1	23591	40827
-	CL-DF	-	AL	21.0	26157	28061
CL-DF	CL-DF	-	-	2.5	589	439
M	M	M	M	-	-	-
-	CL	-	AL-SCL	10.3	52957	30793
SP	SP	-	M	16.6	53158	15979
C-I	C-I	-	M	12.5	48650	18638
Closed System		Reverse Osmosis		3.0	4439	1332

TREATMENT CODES

C = centrifuge
CL = clarifier
DF = disk sludge filter
I = incenerator
AL = aerated lagoon
SCL = secondary clarifier
SP = sludge pond
M = to municipal plant

IV. Groundwood
1. Unbleached
2. Bleached

V. Deinking Mill

VI. Paperboard (No Deinking)

VII. Paper Manufacturer (from purchased pulp)
1. Coarse
2. Fine (8% filled)
3. Book (8% filled)
4. Tissue
5. Specialty
6. Wastepaper

VIII. Glassine, Grease Proof

A number of the region's groundwood mills now use aspen partially or entirely for their pulp source. The ubiquitous aspen was first harvested for pulp by an enterprising Fox mill operator in the 1880s. (Aspen was also one of the first woods used in the earliest wood pulping in the North-east.) But aspen did not receive much recognition as a pulp log until the 1930s. By 1948 refinements in pulping technology had increased the use of aspen to 22% of the total volume of pulpwood.[22] Today aspen comprises 50% of the pulpwood cut in the Lake States[23] and is a staple for several groundwood and sulphite mills on the Fox.[24] It is regularly used for writing and printing papers. In certain tissue mills it is the preferred pulpwood, though mixed hardwoods are now tending to displace aspen for tissue making.[25]

Aspen has several factors in its favor as a pulp material. Its "...short fibers permit a fine surface, good formation, porosity and excellent printability in book and fine papers. In tissue and toweling papers, they add softness and absorbency."[26]

In addition, aspen is easily pulped by any of the commercial processes.

> In fact, it is the wood most often used in development work because of the general feeling that if you cannot pulp aspen with the technique under development, you most likely do not have a viable plan or program.[27]

The years of World War II fostered new uses for paper, and paper packaging rapidly replaced wooden and metal containers. But the war had also spurred a new plastic technology based on cheap supplies or petroleum. It was not long before various plastic wrappings were competing with paper in the packaging department.

In the late 1950s the general expansion of the national economy was reflected in the U.S. paper industry which grew (with the exception of newsprint) at a rate of about 5% per year until 1968.[28]

8.3 FUTURE PROSPECTS FOR PULP AND PAPER

Currently, the paper industry, like every other industry, is facing the forces of recession. Paper consumption in the U.S. (and most other countries where there are no restrictions) tends to parallel the GNP and its changes:

> ...The greater the volume of industrial production, the greater the amount of paper required for industrial use, for packaging and wrapping, for advertising in newspapers and magazines, and for writing purposes.[29]

> ...As more care is devoted to the protection of goods in transit and for retail sale and the standard of living rises, more lavish standards of packaging tend to be adopted and more paper and paperboard is used to pack a given volume of goods handled.[30]

However at such time that there is decline in national income, "many of the uses of paper, especially for wrapping goods sold retail are not strictly essential and can be dispensed with without seriously impairing the economy."[31]

In addition the uses of paper for advertising purposes often decline during a recession. In fact, these effects are already being felt by magazines. The Wall Street Journal (December 23, 1974) claimed "...the volume of first quarter magazine advertising...will in most cases, be off considerably from the 1974 period. ...Businesses facing possible profit erosion in the new year are turning to their advertising budgets for savings."

The production of boxboard and industrial papers is linked with levels of output of consumer nondurables and output of all goods respectively. Building papers and boards depend on the strength of the construction industry which is currently in a slump.[32]

Two of the major paper products in the Green Bay area are sanitary and tissue papers and fine writing and print papers. While production and consumption of sanitary papers is primarily population dependent, the manufacture of writing papers is related to disposable personal income.[33]

In 1973, a number of factors -- such as shortages of wood pulp and Canadian newsprint strikes -- caused a situation of high demand and limited supply in the paper market. Consequently, 1974 was, at least for a while, a year of high production for the paper industry as it attempted to catch up with demand.

> "As a result of supply contraints in 1973, the paper industry entered 1974 with an unfilled inventory demand by end-users in all channels of distribution from the paper maker to the final consumer."[34]

But by the end of 1974, production was dropping rapidly and paper makers were feeling the effects of inflation.

> "What at one time seemed like skyrocketing demand for an insatiable consumer was turning out to be, more and more, a buildup of inventories. The pace of production throughout the system was temporarily hiding the fact that final demand was off."[35]

The industry's earnings remained down during the first quarter of 1975 with a 34% loss in profits during the first six months of the year.[36] Industry economists have predicted that inflation, shortages of energy, pulp and other materials, and a slow down in U.S. population growth will cause a generally slower rate of paper industry growth over the next 15 years as compared to the last 15 years. For the short term, industry managers are hesitant to invest in plant expansions. Their attitude is one of "wait and see", and some expansions planned in 1974 have since been postponed.[37]

With Green Bay region mills selling to a nationwide market (their largest markets, however, are in the Midwest[38]), their prospects for gradual expansion are fairly good over the long run. However, these expansions are expected to be internal since the limited supplies of raw materials would not justify the building of new mills.[39]

8.4 ENVIRONMENTAL IMPACTS OF PULP AND PAPER

Large quantities of clean water are essential to paper manufacture; the pulp and paper industry ranks third in industrial water demand. At least 90% of the water used in paper processing is returned to the environment as a byproduct or as waste water. If untreated, this waste water carries back to the river or stream all those organic materials that are contained in unrecovered spent pulping liquor.

Spent pulp liquors contain wood sugars, acetates, lignin compounds, and other products of pulping (depending on the process used), all of which are unstable oxygen-demanding compounds. These substances as well as organic materials in paper wash waters, put a great burden on the dissolved oxygen levels in the receiving water way. Sometimes, particularly in summer, the aquatic oxygen supply may be totally depleted by the combination of warm temperatures and high waste loads. Additional non-organic and relatively inert organic wastes known as suspended solids (s.s.) are also discharged by pulp and paper mills. These include bark, wood particles, coating clays and dyes. While paper and board mills have high s.s. loads, pulping mills generally have the highest BOD discharge.[40]

The wastes of both types of operations contain large amounts of nitrogen and phosphorus compounds. In the lower Fox River, nitrogen discharge from mills is about equivalent to the discharge from municipal sewage plants. About 90% of the nitrogen load from the mills on the Fox is discharged by Charmin Paper mills. However, this mill is being coupled into the Green Bay Metropolitan Sewerage system and will be essentially eliminated as a major nitrogen source.[41] Phosphorus discharge from the mills is of less concern than either nitrogen or high BOD materials. In fact, phosphorus discharge from the mills is considerably less than that found in sewage outfalls (Table 43).

Table 43. Comparison of Sewage Plant and Pulp Mill Nutrient Loadings to the Lower Fox River

	NH_3-N		NO_3-N		TOTAL-P	
	Lb/Day	Kg/Day	Lb/Day	Kg/Day	Lg/Day	Kg/Day
17 Pulp and Paper Mills	8,052	3,652	598	268	1,078	488
9 Sewage Treatment Plants*	4,408	2,000	597	272	2,094	949

*Nitrogen data include NO_2

From P.E. Sager and J.H. Wiersma, "Nutrient Discharges to Green Bay, Lake Michigan from the Lower Fox River," Proc. 15th Conf. Great Lakes Research, 1972.

Nutrient discharge from the mills is troublesome. But the biggest problem in the pulp and paper industry continues to be effluent with high BOD. For many years pulp and paper mill effluents were dumped untreated into the Fox, Menominee, Peshtigo and Oconto Rivers without stirring any public response. The Fox especially received large loads of waste. Being a river with a large volume of water it had a large capacity for assimilating and flushing wastes. But as the industry grew and the population of the Fox-Wolf valleys also grew, the waste load in the Fox reached an objectionable point. By 1925 the oxygen-demanding wastes of the paper mills were being blamed for massive fish kills in the Fox and Lower Green Bay.[42]

In 1927 the state legislature established the State Committee on Water Pollution, which was given powers to investigate pollution sources, hold public hearings and issue abatement orders.[43] In 1929 this committee investigated thirty paper mills on the Fox and issued its first cleanup orders.[44] In 1939 the quality of the Fox was reassessed and found wanting.[45] Again the paper mills were judged largely responsible. Ten years later the committee's field staff was enlarged, but increasing effluent loads kept ahead of abatement measures. In addition, there was reluctance to strictly enforce pollution laws. Pulp and paper was an important local employer. (In 1966, the industry employed 14,000 employees in the Fox-Wolf region, approximately 12% of the region's total employment.[46]) In the absence of any federal pollution law, the industry could threaten to take its operation to Canada or some other place where water quality was not an issue.

In 1952 a team of scientists repeated the water quality measurements that had been made in 1939. It was clear from the results that the Fox River and Lower Green Bay had deteriorated badly over the thirteen-year period.[47]

The late 1950s and early 1960s saw growing public concern over the polluted condition of major waterways. There was a subsequent response by industry in the form of intense research on abatement technology and by government in the form of Wisconsin's 1965 Water Resources Act,[48] the Federal Water Pollution Control Act of 1967 (FWPCA), and, later the FWPCA Amendment of 1972.

The latter amendments require that,

> ...all states adopt water quality standards compatible with the objectives of that Act and effect an upgrading in the general quality of waters. In accordance with the Federal WPCA Amendments and existing rules for revision of state water quality standards, the Department of Natural Resources has revised the water quality standards in Chapters NR102-104 of the Wisconsin Administrative Code. In broad terms, the regulations would bring minimum standards on nearly all water courses to at least the fish and aquatic life level.[49]

The Fox River is by far the greatest source of nutrients and waste loadings on Green Bay and the one which has received the most attention from the Wisconsin Department of Natural Resources. The lower 29 miles of the Fox River support the largest concentration of pulp and paper mills in the world. In 1967 90% of the 315,000 lbs per day of total five-day BOD entering the Lower Fox River came from industrial and manufacturing sources. Currently, the Wisconsin Department of Natural Resources is completing issuance of water pollution permits to pulp and paper mills on the Fox and other rivers entering Green Bay. The permits are based on the Environmental Protection Agency's interim water quality guidelines which set limits on BOD and suspended solids permissible in discharge waters per ton of product. (See Table 44)

Table 44. Interim Effluent Limitations for Pulp and Paper Mills (In Pounds per Ton of Production)

Subcategories	BOD	Suspended Solids
1) Kraft Pulping and Manufacture of:		
a) Coarse Paper and Liner Board	5	5
b) Newsprint	5	6
c) Bleached & Unbleached Grades	9	10
d) Bleached Grades	11	10
2) Sulfite Pulping and the Manufacture of:		
a) Paper	35	20
b) Dissolving Pulp	65	20
e) Neutral Sulfite Semi-Chemical	14	8
4) Groundwood		
a) Unbleached	2.5	5
b) Bleached	4.5	9
5) Deinking Mill	10	16
6) Paperboard (No Deinking)	3	3
7) Paper Manufacture (from Purchased Pulp)		
a) Coarse	2	3
b) Fine (8% filled)	6	7
c) Book (8% filled)	3	4
d) Tissue	8	6

For all subcategories settleable solids shall not exceed 0.1 ml/1.

[1] Groups 1, 2, 3 and 4 refer to integrated mills (combined pulping and papermaking operations.)

[2] Groups 5 and 6 refer to wastepaper processing plants.

From Wisconsin Register, March, 1974, No. 219, Environmental Protection

Compliance on these permits is expected in 1977. At that time the guidelines may be revised and permits will be reissued, probably on a load allocation basis.[50] The DNR is now preparing a mathematical model of the Lower Fox that takes into account the regular BOD and suspended solid loads of each respective point source. Assuming the model works successfully, the next issuance of pollution permits will see each mill required to meet its proportional share of cleanup. This could mean a tightening of some present permits and a relaxing of others.[51]

Since each of the smaller rivers entering Green Bay has only one or two major point sources, load allocation permits have already been issued for these waste dischargers. These include the Scott Paper mill at Oconto Falls on the Oconto River, the Badger Paper mill at Peshtigo on the Peshtigo River, and the Scott Paper operation at Marinette. In terms of pollution, the Oconto and Peshtigo plants are of greatest concern. However, pollution levels on the Oconto, Peshtigo and Menominee are not expected to increase and probably will decline.

The DNR's ideal would be to achieve the state standards and maintain a level of at least 5 ppm dissolved oxygen in Green Bay and its tributary rivers and to make the waters habitable for fish and wildlife.[52] However, the DNR has recognized that meeting this goal along portions of the Fox and Oconto Rivers is almost impossible because of the high economic costs of abatement. Those areas where standards have been modified are termed "water quality limited." This means that to meet the water quality standards of 5 ppm D.O. would necessitate the mills, or municipalities, installing higher levels of effluent treatment than the law requires. Water quality limited areas on the Fox River are shown in Figure 56.

Despite the downward adjustment of standards, most industries on the Fox are still having to reduce their effluent levels in order to meet the new standards. And, because strict pollution control standards have been overdue, the costs of catching up have been high for the paper industry.

> In the decade prior to 1972, environmental spending by the Wisconsin pulp and paper industry was set at $70 million. At that time the forecast was that another $50 million would be spent on environmental protection in the immediate future.
>
> However, a survey shows that in 1972 alone capital and operating expenditures for water pollution abatement came to $26,282,632. On air pollution equipment, the figure was $8,258,211. This totals more than $34-1/2 million for the one year.
>
> In 1972 through 1975, an additional $82,653,006 was expected to be spent on water pollution abatement, and $24,104,075 on air. This total is close to $107 million.[53]

Some companies have had to shut down marginal operations that would have become uneconomical if brought up to pollution standards. These plants, like Kimberly-Clark's sulfite mill on the Fox and their mill at Niagra, are generally smaller, older and less profitable mills. But they are mills that probably would have continued operating several years longer had not environmental considerations become an issue.

The present water quality standards, along with inflation and pulpwood shortages, have put a damper on paper mill expansion. In cases where a pulp mill actually has to shut down, it often means the parent company must buy its processed pulp from other manufacturers.[54] Assuming that the DNR stands firm on its standards, a company wishing to expand its pulp or paper output in the future will either have to disperse its pulping operations to less waste-loaded rivers or further improve its waste-water treatment facilities.[55]

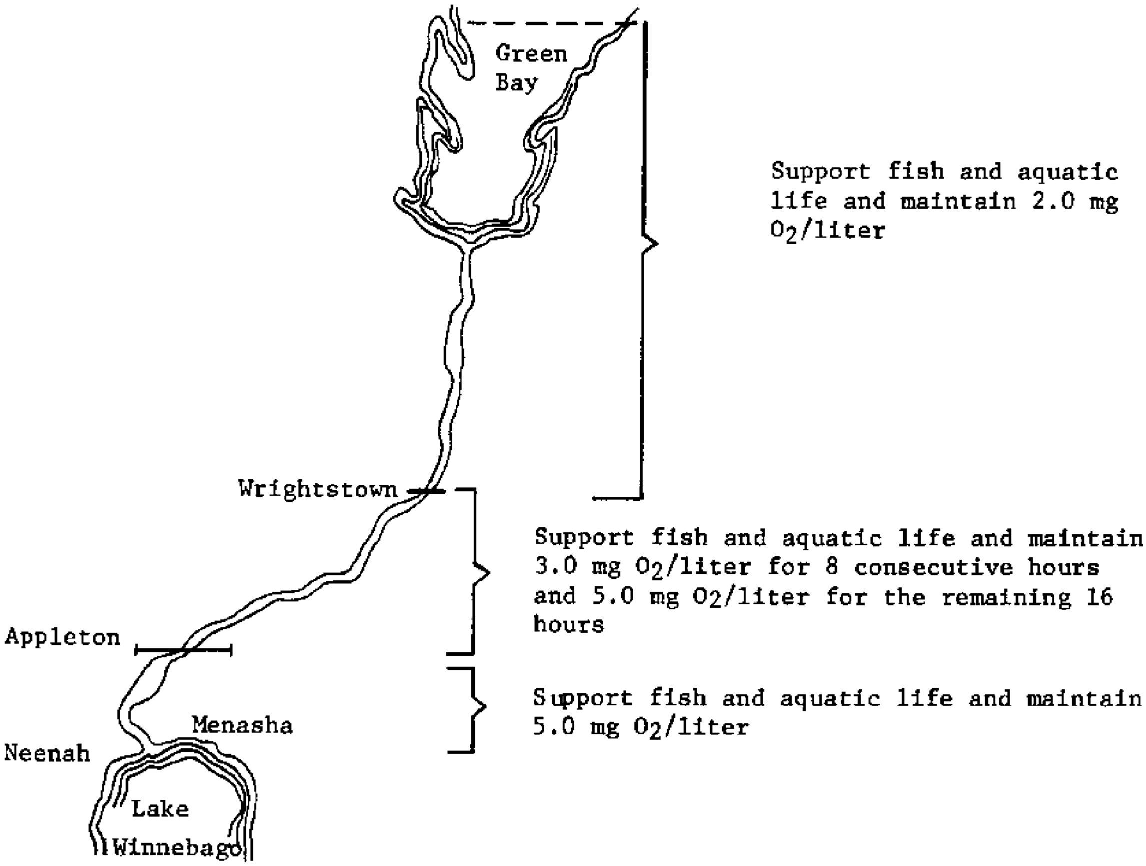

Figure 56. Water Quality Limited Areas of the Lower Fox River and Green Bay.

Based on Chapters NR 103.05 and NR 104.04,"Interstate Waters, Uses and Designated Standards," Natural Resources, Wisconsin Administrative Code.

Conflicts between paper companies and the DNR have already developed. Fort Howard Paper Company announced its intention to expand pulp production by 450 tons per day. The DNR claimed this expansion would reduce the excellent efficiency of Fort Howard's waste disposal system and put the plant's effluents in excess of water quality guidelines.[56] For the time being, Fort Howard has abandoned its expansion plans for Green Bay.

Kimberly-Clark is also challenging DNR standards in a case currently subject to a hearing.

As of January 1975, the DNR had brought suit against Consolidated Papers at Appleton for exceeding its allotted discharge of suspended solids on several occasions in 1974 and for failing to monitor its wastes as required by permit.[57] The DNR appears determined that any increase in plant production be accompanied by an equivalent increase in waste removal efficiency and that water quality remain at its present levels, at least. However, with unemployment an increasingly important question, and with 36% of the employment in Brown, Outagamie and Winnebago counties based in paper and allied products,[58] some compromises may have to be made.

It should be pointed out that pulp and paper technology has moved ahead rapidly in the last fifteen years both in the area of water pollution control and in the recycling of processing water. Working within the limitations of high production costs, shortages of water in some areas, and stream pollution regulations, a number of plants have gone to "closed systems" which reclaim fine waste fibers and recycle as much water as possible.[59] One papermaker has predicted that future advances may make paper mills almost "waterless."[60] In the Green Bay area, several mills are at or near zero water usage.[61]

Although there has been some noticeable progress and improvement in BOD loadings in the Lower Fox River (Figure 57), abatement under present economic situations is not progressing as rapidly as had been forecast. It should be noted that significant pollution of the Lower Fox River, and consequently of Green Bay, continues at present. But with rigorous adherence to existing abatement standards, this aspect of Green Bay's pollution could be adequately solved within the next decade.

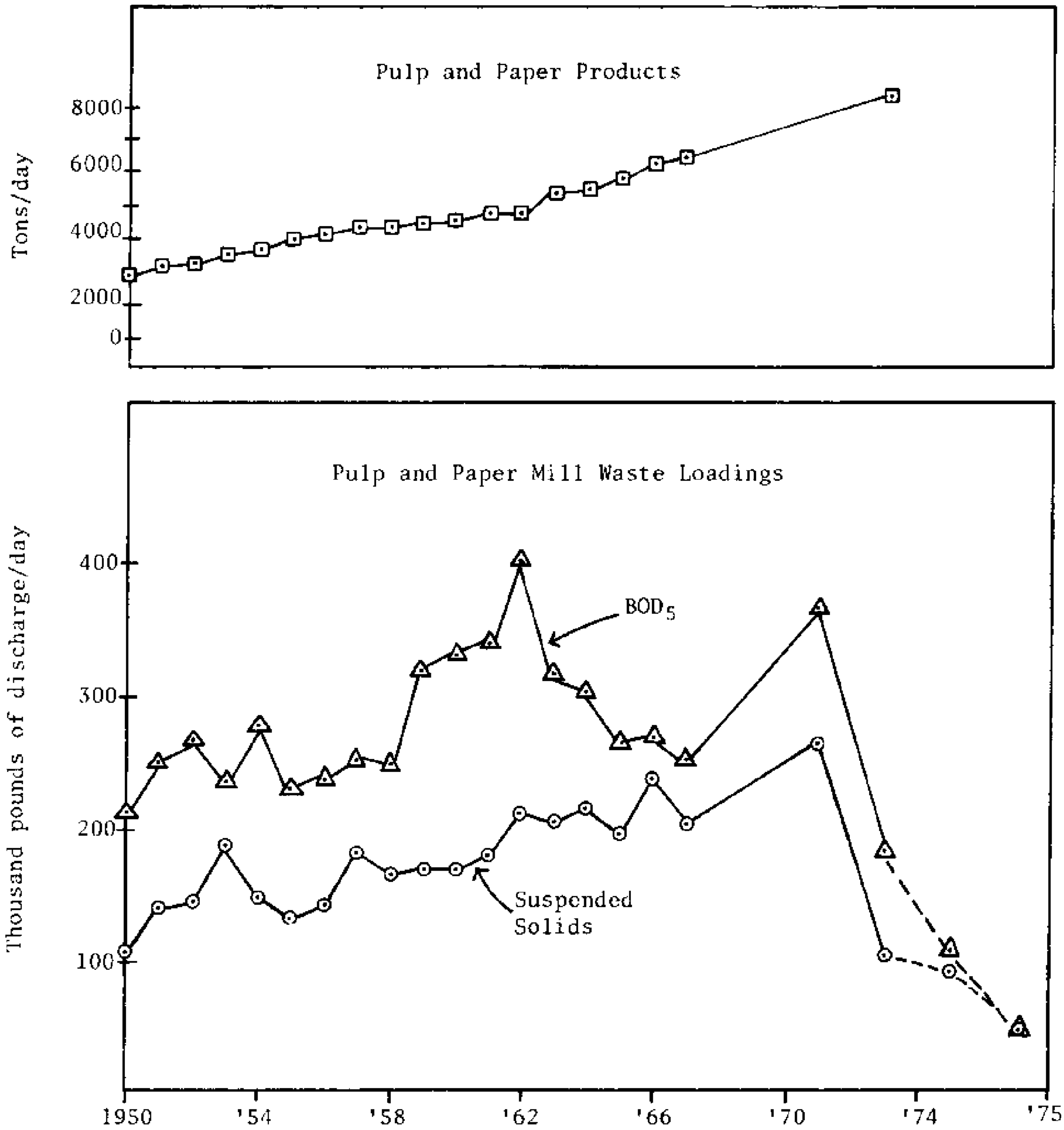

Figure 57. Comparison of paper and pulp production and waste discharge in the Lower Fox River (1958-1974).

From E. Epstein et al., Lower Green Bay: An Evaluation of Existing and Historical Conditions, U.S. Environmental Protection Agency, Region V Enforcement Division, Report No. EPA-905/9-74-006. 1974.

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9. AGRICULTURE

9.1 HISTORY

The agricultural settlement of the Green Bay region came slowly compared to other areas of Wisconsin. The southwestern lead mining region was settled early in the 1820's by adventurers from Illinois, Missouri and Kentucky. The southeastern farmlands also were bought up rapidly in the 1840's and 1850's by New York and New England migrants after Wisconsin had become a state.[1]

But the northern counties remained sparsely populated until the end of the Civil War when the lumber boom began in earnest. Even then, the availability of cheap lumber from the northern pineries via the railroad lines encouraged more settlement on the distant prairies than in the woods themselves.[2]

However, the lumber mills and camps of the Green Bay region did offer a new market for farm produce. This gap was filled by farmers already established in Brown and Winnebago Counties and by migrants coming into the area. Not only did the lumber camps pay good prices for the produce, but they also provided winter employment for a farmer who could swing an axe or manage a log sled and ox team.

> Thus, the advantages of farming in the neighborhood of big and fairly permanent lumbering establishments. . . made so strong an attraction that wherever good land could be obtained in proper locations it was sure to be taken up as soon as possible after the mills began operations.[3]

The earliest farms were established in the lower counties of the Wolf River watershed. Here numerous oak openings mingled with the pine and offered good land with minimal clearing. Further north, farms were fewer and scattered, for even when the pine woods were cleared, the cost of removing stumps was too high.[4] Most farmers settled on the edges of the pineries and sledded their stocks of flour, pork, beef, potatoes and animal feed into the winter logging camps.

In Wisconsin, settlement was encouraged by the State Board of Immigration which distributed brochures in several languages describing the merits of each county.[5] The federal lands in the northern counties sold for $.75 and $1.25 an acre during the 1870's. Their settlement was facilitated by the extension of railroads up the western shore of Green Bay. The railroads also gave farmers a route by which to ship excess crops south to urban markets.

For the early farmers who came from New York, Pennsylvania and Ohio, wheat was the traditional crop. Wheat culture grew rapidly in Wisconsin in the 1840's, a time when all available surplus was being exported to Britain.[6] Expansion of wheat growing was encouraged by the invention of reaping machines, the extension of the railroads and the domestic food crisis of the Civil War years. Drought in 1858 and 1859 slowed expansion only temporarily. More acres went to wheat and more acres were lost to rust, smut, chinch bugs and bad harvest weather. By 1879, wheat had become an incidental crop in most of southern Wisconsin and had been largely replaced by corn, oats and hay.[7] Wheat contined to be produced as a minor crop in the northern areas, however, where it was better suited to the cooler climate.

The trend to grain and hay crops followed an awakened interest in livestock raising, especially of pigs, cattle and horses. Sheep raising had been popular for a period but was on the decline by 1870. The wool had been shipped via the lake ports and Erie Canal to mills on the East Coast but extreme price fluctuations eventually discouraged Wisconsin wool growers who sold their fine wool herds to the western ranges.[8]

Swine were always present in Wisconsin, but most of them were the semi-wild "prairie racers" from the woods of Indiana. They were lean, tough, bristle-backed and troublesome. Not until 1870 were recognized breeding stock present in any quantity.[9] The new stock, fattened on Wisconsin corn and put through rigorous breeding, produced vastly improved animals. The favorite breeds were Poland Chinas, Jersey Reds, Suffolks and Berkshires.

> Hogs, indeed, saved the careers of thousands of Wisconsin farmers brought to the verge of bankruptcy by unwise persistence in wheat raising; so that the arresting term "mortgage lifters" not ill-applied to the porcine branch of farm livestock.[10]

Dairying, a business which required capital and know-how, came to the state only gradually. Prior to the Civil War, farm cattle were few, ill-cared-for, and of inferior stock.[11] Little provision was made for their fall and winter feed, and their products were usually consumed on the home farm.

Raising cattle on a commercial scale required (1) the development of markets for dairy products, (2) the skills of cheese and butter making, (3) the introduction of clover and timothy into pasturage to provide fall and winter feed, and (4) programs of breeding and agricultural education, and a county fair system. These factors all began coming together in the 1870's.[12]

By then, southern county farmers, particularly those from New York who had some background in dairying, had begun to sell butter at a good profit to Chicago and Milwaukee markets. Some had begun plans for a factory system of cheesemaking.[13] Though the "rank and file" of

Wisconsin farmers were still carrying on in the old way, they eventually fell into line. Joseph Schafer, an early agricultural historian, attributed Wisconsin's eventual primacy in this area to:

- the initiative of New York-bred farmers
- the establishment of the Wisconsin College of Agriculture
- the dogged following of good dairy practices by foreign-born, rather than native American, farmers
- the leadership of William D. Hoard, publisher of Hoard's Dairyman.[14]

Hoard was influential in organizing the Wisconsin Dairymen's Association and opening new eastern markets to Wisconsin cattlemen.

> The opening of these markets has encouraged many of the best farmers to devote their attention solely to this profitable branch of agriculture. . . . This also means the immediate and permanent enriching of the soil as it is not impoverished by the raising of grain and a manure of the highest grade is returned to it, enabling its fertility to be continually increased instead of depleted.[15]

This advocacy would turn into a major environmental issue for Green Bay several generations later.

Hoard urged "breeding sharply for milk" rather than keeping meat-and-milk cattle like the Devon and Ayshire, the popular "dual purpose" breeds of that day.

Because dairymen in the Green Bay region were too far from the major fresh milk and butter markets of Chicago and Milwaukee, they turned to cheese as their major product. By the turn of the century, the Fox and Lower Wolf River Valleys had become cheese processing centers.[16] (Figure 62) Brown County, which had produced only a single cheese in 1850, could boast of 4,265,040 pounds of cheese by 1910. By 1927 that amount had more than doubled and Brown County alone had 49 cheese factories, 28 butter factories, and 9 condenseries.[17] The Fox and Wolf Valleys remain important dairy centers with a count in 1970 of 6 creamery plants, 77 cheese factories (10 of them with 50 or more employees), 9 condensed or evaporated milk plants and 4 ice cream processors.[18]

The distribution of farm crops across the Green Bay watershed is determined primarily by soil and climate. The Fox and Lower Wolf River Valleys are favored by soils of good to excellent agricultural quality.[19] (Figure 58) These are primarily pink, reddish brown clay loams, with occasional small areas of black silt loam, muck and peat. These soils are well suited to dairying, both for pasture and feed crops. There is also a considerable amount of land in peas, corn and beans for canning and freezing.

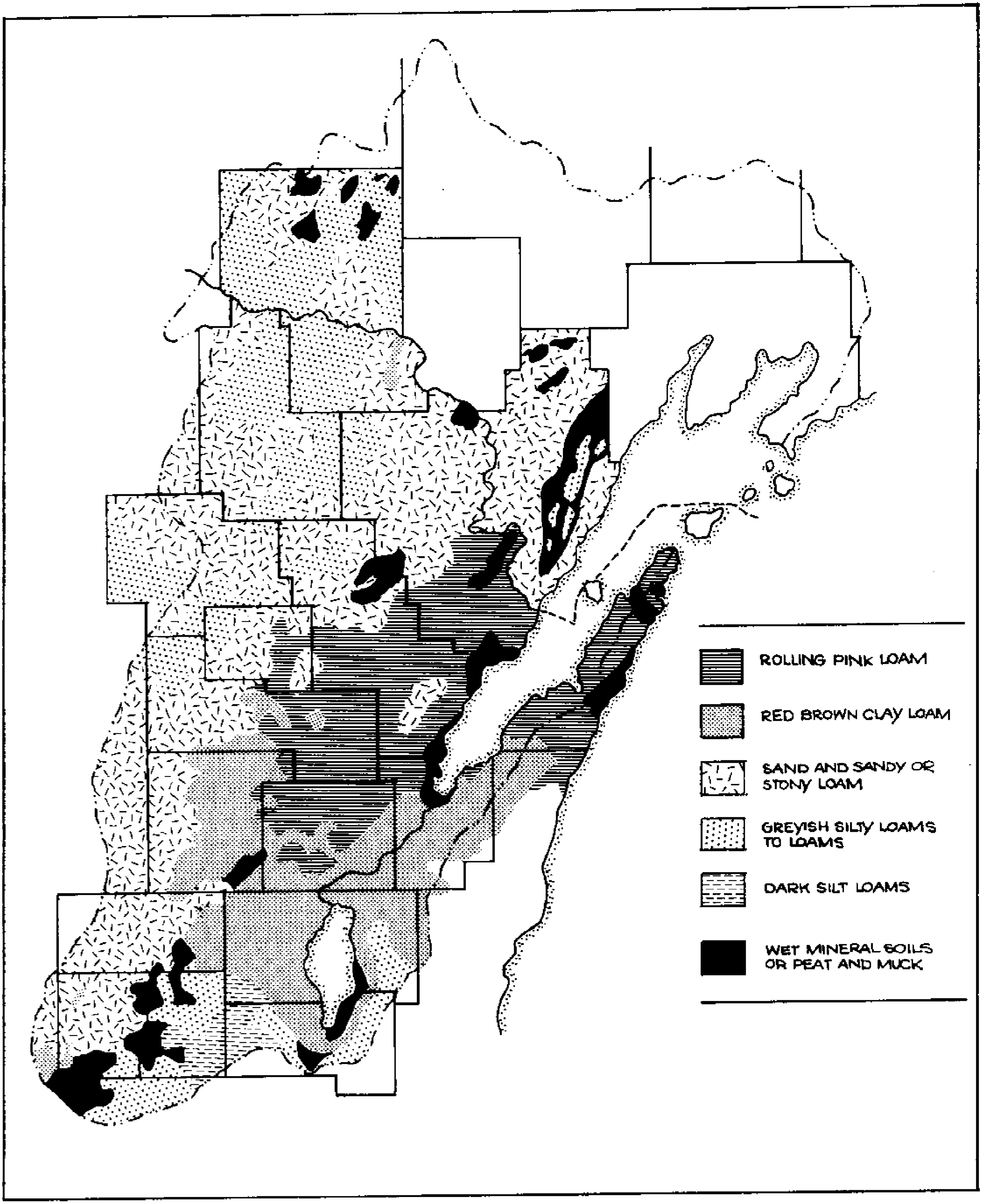

Figure 58. Soils of the Green Bay Watershed

From Soils Map of Wisconsin, Wis. Geol. and Nat.Hist. Survey.1966; and E.J. Senninger, Atlas of Michigan, 1970.

The lower basins of the Menominee, Peshtigo and Oconto Rivers and the eastern branches of the Wolf are covered by pink sandy loams.[20] The main crops are corn for silage, sweet corn, hay, peas for canning, and milk products.

The northern upland areas of the above rivers are covered by a patchwork of reddish-brown sands and greyish loams.[21] These soils are ill-suited for agriculture. The sands are droughty and acid, have low fertility and are easily eroded by wind. The grey silt loams and sandy loams are often poorly drained and of low fertility. Irregular slopes, stoniness and short growing seasons severely limit their agricultural use.

Similar poor soils occur in Michigan's Upper Penninsula where droughty, acid, greyish loams and sandy soils are interspersed with areas of wet mineral and organic soils.[22] The sandy soils, when irrigated and fertilized, are satisfactory for raising potatoes, of which the region is a fair producer. Other crops of the region are hay and dairy products.

Infertile areas of Michigan's Upper Peninsula and the northwestern sections of the Wolf, Oconto and Peshtigo watersheds in Wisconsin were originally "settled up" in the early 1900's by unsuspecting newcomers. Though the northern forest areas were not choice agricultural lands, their value began to rise with the advent of World War I and the decline of the lumber industry.[23] By then, the Wisconsin College of Agriculture had perfected the method for blasting out pine stumps with dynamite and had tested most of the northern soils for productivity potential.[24]

As the lumber companies cleared out areas of forest, they would put the land up for sale as farmland. Many German, Scandinavian and Irish immigrants bought these cheap lands with the aid of the Homestead Act. The new settlers could raise crops, sell any surplus to the mills and take employment as loggers or fishermen in winter.

Land companies and other agencies promoted the cut-over pineries as the future center of a great dairy empire. Though much of the land was good, too many "forties" with submarginal soils were sold to innocent immigrants. Settlers on the poorer lands had a chance to turn a profit while the war kept prices high, but they inevitably went broke when the depression hit, if not sooner.[25]

> It has been said that Michigan afforded the "landshark" an opportunity to work in a way not equalled in any other locality in the country. As a result, Michigan cut-over lands are noted for abandoned farms.[26]

A survey of Marinette County in 1930 showed that of the county's 2,307 farms, 23 percent were abandoned.[27] These farms became tax delinquent and under the Forest Crop Law in Wisconsin and the Pearson Act in Michigan were picked up by the counties and state, respectively, for conversion to their most appropriate use--as timberland (see discussion of timber industry today , pp. 181-187)

The Upper Peninsula counties have now reverted almost entirely to forest (Figure 59). The exception is Menominee County which, with about 30 percent or its land under pasture or cultivation, is one of the Peninsula's prime agricultural areas.[28] Besides dairying, hay and potatoes are grown.[29] Delta County is almost completely devoted to forestry, as are the other Peninsula counties. Many farmers in the region work part time in the pulpwood business. In Wisconsin areas too, at least half the farmers also hold non-farm jobs.[30]

The abandonment of farms which began in the 1930s has continued into the present. Between 1950 and 1959, almost 3,600,000 acres of farm holdings in the northern Great Lakes area moved out of cultivation.[31] In some cases, the lands have gone to local government for forestry purposes. In Wisconsin, the lands now in county forests total over 2 million acres.[32] In other cases, derelict farms have been broken up and sold for recreation and second-home use. Some land, of course, has been picked up by more aggressive farmers who are able to farm it economically in combination with their other holdings.

The decline of farm acreage in the northern counties appears to be a fairly permanent net loss of farmland.[33] The loss of agricultural services and facilities which accompanied the abandonment of farms makes a rapid resurgence of agriculture highly unlikely. As one observer has commented:

> Where several hundred active farms in a locality once made the operation of a feed store, farm equipment store, or processing plant a profitable enterprise, the decrease in the number of active farms may alter the situation and cause a loss of these necessary service facilities.[34]

Though the loss of farm land in the northern counties is blamed on the high cost of farming poor soils under less than ideal weather conditions, the recent losses of farm land in the southern Green Bay area counties are based on a search for economies of scale in an area of rapidly rising land values. There is a trend statewide toward larger but fewer farms.[35] This means that the farms which are expanding are practicing a more intensive and highly mechanized agriculture. There is also an increase in farms under corporate ownership.

Dairy herds, too, are being consolidated. While the number of herds fell by 25 percent in the last five years, the number of cows has declined only slightly and the number of cows per herd has increased[36] (Figure 60).

There has also been a decline in fresh vegetable production statewide, including the Green Bay region. Due to the perishable nature of fresh produce, the crops must be grown close to urban wholesale and retail outlets. But proximity to urban centers puts vegetable farms and orchards in competition with urban-suburban land uses.[37] The resulting high taxes have driven farmers off the land.

As vegetable production has dropped, so has the number of food processing plants. But again, the decrease in numbers is balanced by an increase in size as plants attempt to benefit from economies of scale.[38]

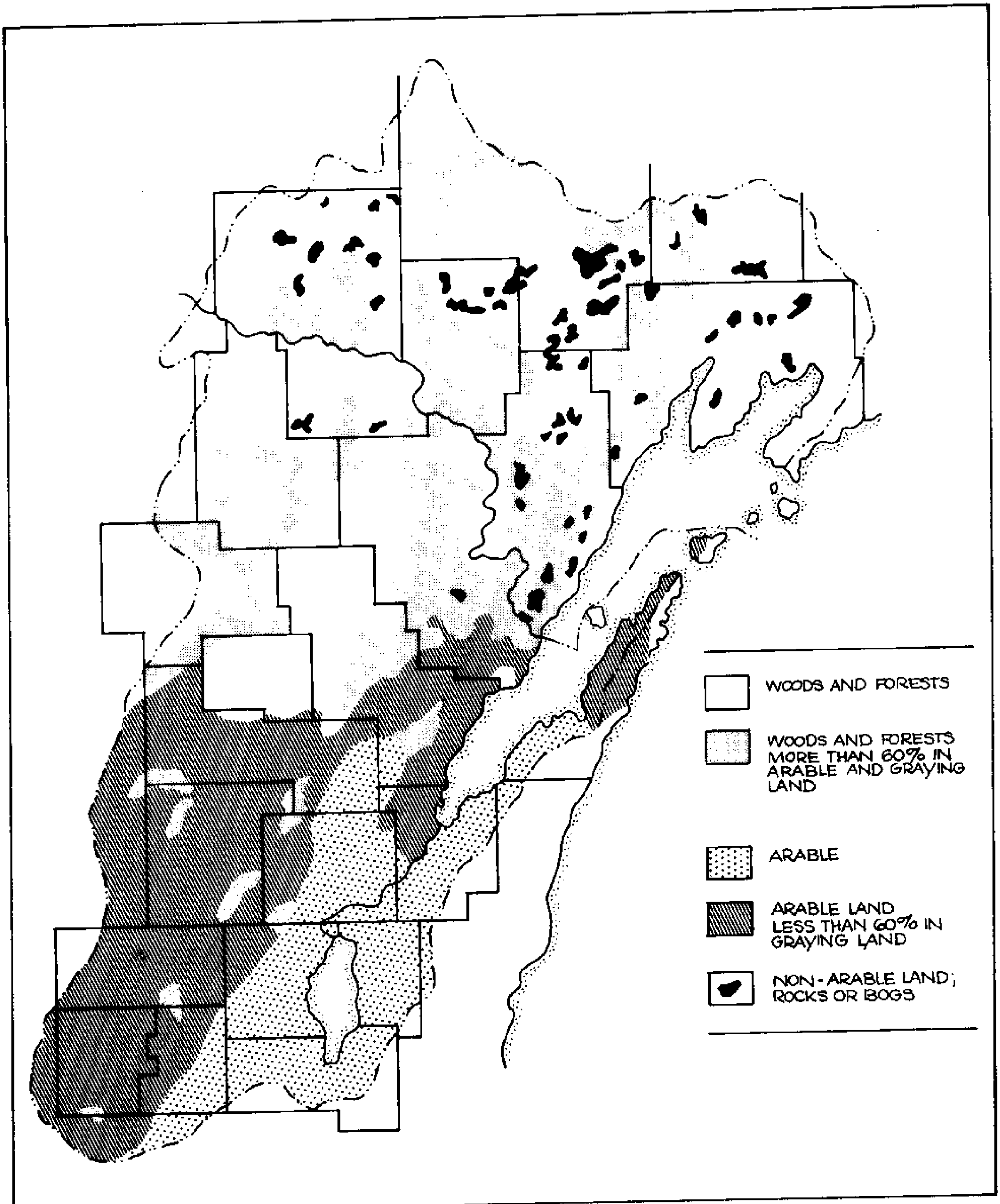

Figure 59. Land Use in the Green Bay Watershed

From World Atlas of Agriculture, 1970.

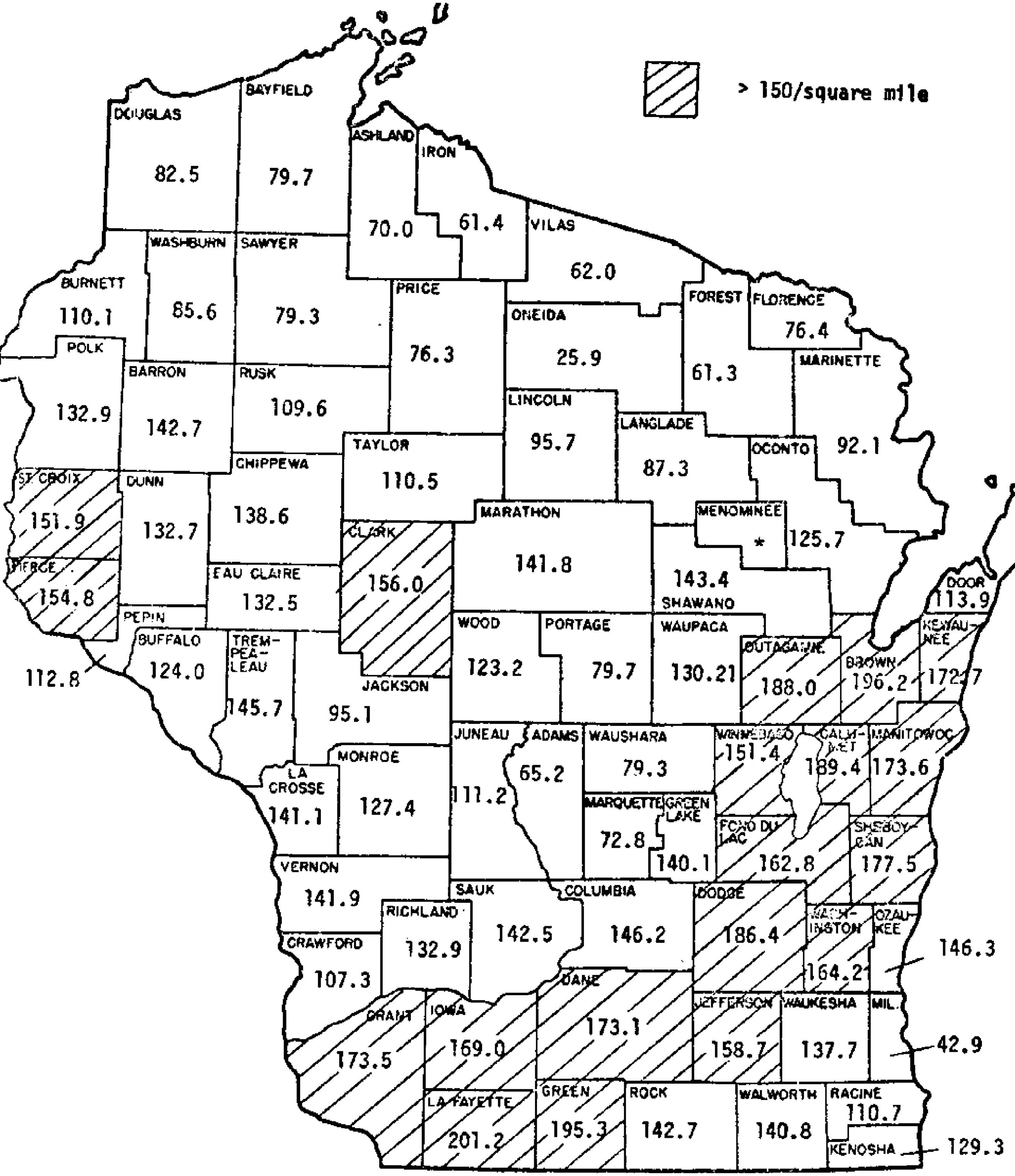

Figure 60. Density of all Cattle and Calves per Square Mile of Farm Land (1969)

From U.S. Bureau of the Census. 1969 Census of Agriculture. Volume I, part 14, Section 1, County Data, Wisconsin.

9.2 IMPACTS OF AGRICULTURE ON GREEN BAY

Agriculture in the Green Bay watershed has a number of impacts on the Bay itself. Most of the impacts are characteristic of agriculture's effect on waterways throughout the state.

For example, as the number of cows per herd increases, there is an increased concentration of animal wastes per herd. Calculations for animal wastes generated by Calumet County farms offer some interesting figures:

> In 1969 Calumet County (bordering Lake Winnebago) had 99.5 milk cows per square mile of farm land. Daily production of manure from these cows approaches 9,000 pounds per day per square mile of farm land. Alternatively, the 28,711 milk cows in the county in 1969 produced 2,583,990 pounds of manure per day. This is over 43,000 cubic feet per day--or the equivalent of covering an acre of land slightly less than 12 inches deep with manure. This bulk manure contains, on the average, 218,203 pounds of organic matter. Additionally, we know that this adds 12,920 pounds of nitrogen, 2,584 pounds of phosphorous and 10,336 pounds of potassium per day to the land.[39]

In addition, Wisconsin beef cattle numbers are on the rise, many of them feed-lot raised cattle.[40] This also poses a problem of concentrated animal waste disposal.

Large amounts of animal wastes unless carefully contained, can run off into waterways creating eutrophic conditions. The most common and practical method for disposing of animal wastes is to spread them as fertilizer on crop lands. However, in Wisconsin and Michigan where the ground freezes in winter this poses serious problems of nutrient runoff in the spring. Sager and Wiersma demonstrated the size of the problem in a study on Apple Creek, a tributary of the Fox River.[41]

Apple Creek drains approximately 35,300 acres of primarily agricultural land in Brown and Outagamie Counties. Phosphorous loads entering the creek ranged from 0.15 pounds per acre in summer to 3.0 pounds per acre in spring. Multiplying these averages by the total rural acreage in the lower Fox watershed, the investigators found that rural runoff was the major phosphorous contributor to the Fox River during the spring (See Figure 61). Most of the phosphorous came from animal waste washed off the frozen fields during a few weeks of spring rain and snowmelt. During summer and fall, the rural lands were only minor phosphorous sources.

Unfortunately, the high cost of alternate disposal systems, such as facilities for the liquefication and storage of winter manure, exacerbate "the already tenuous competitive position of the small livestock operator."[42] Many small operators simply cannot afford a special disposal system.

Manure and chemical fertilizer runoff during the spring thaw and summer rains may add nutrients to the Bay directly or to the Lake Winnebago-Fox River system. But the Bay is the ultimate recipient. The runoff also carries with it agricultural pesticides and herbicides which collect in the Bay ecosystem (See discussion on pp.85-88).

Another problem of a continuing nature is the pasturing of cattle on streams. This practice causes loss of vegetative cover and increased erosion of stream banks. This has been a notable problem off and on in the northern counties where there is increased grazing of beef cattle.[43] According to a report by the Wisconsin Department of Administration, grazing of forest lands also persists "despite four decades of forestry extension and a program of minor incentives to curb the practice."[44] Woodland grazing is most common in those forested counties where the cost of land clearing is prohibitively expensive for small farmers. However, the outcome of forest grazing is deteriorated forest productivity and only a minor gain in pasturage.

In the southern portion of the watershed are red clay loams, good agricultural soils, but highly susceptible to erosion.[45] The erosion is often accelerated by the cultivation of corn, a crop whose culture leaves the soil relatively bare for long periods of time. Intensity of farmland erosion varies from year to year, depending on the preferred crop of the season. In Door County, for example, new fast-maturing hybrid corn is replacing to some degree the hay and alfalfa crops which have been traditional in the county. According to the area soil conservationist, the loss of these ground-covering crops will mean greater soil erosion.[46] On the other hand, he sees less erosion in the county's orchards as cherries are replaced by apple trees. Apple orchards are not cultivated for weed control and thus undergo less soil loss. While erosion is not a major problem in the Green Bay basin, even minor erosion in such a large watershed has a significant impact on the sediment sink area, that is, Green Bay.

According to the Corps of Engineers, agricultural sediments make up the largest volume of the sediments that must be dredged from rivers and bays in the Great Lakes Region.[47] The Corps justly complains that this uncontrolled surface runoff accelerates deterioration of downstream water quality and may even cancel out the effects of high level waste treatment by industries and municipalities. The blame for continued erosion is placed by the Corps on the present soil conservation system which must treat erosion on a farm-by-farm basis, relying on the voluntary co-operation of farmers.

> Soil conservation districts have had to operate with farms as they exist. Hence, they normally develop erosion control plans within the rectangular configurations created by the land survey system of the U.S. This lack of relationship to topographic and ecological patterns has limited the effectiveness of control measures when they have been applied. . . .
>
> It is of interest to note that one of the objectives stated in the Soil Conservation Act of 1935 is that of protecting rivers and harbors from the adverse effects of erosion, which apparently reflected Congressional intent. In later

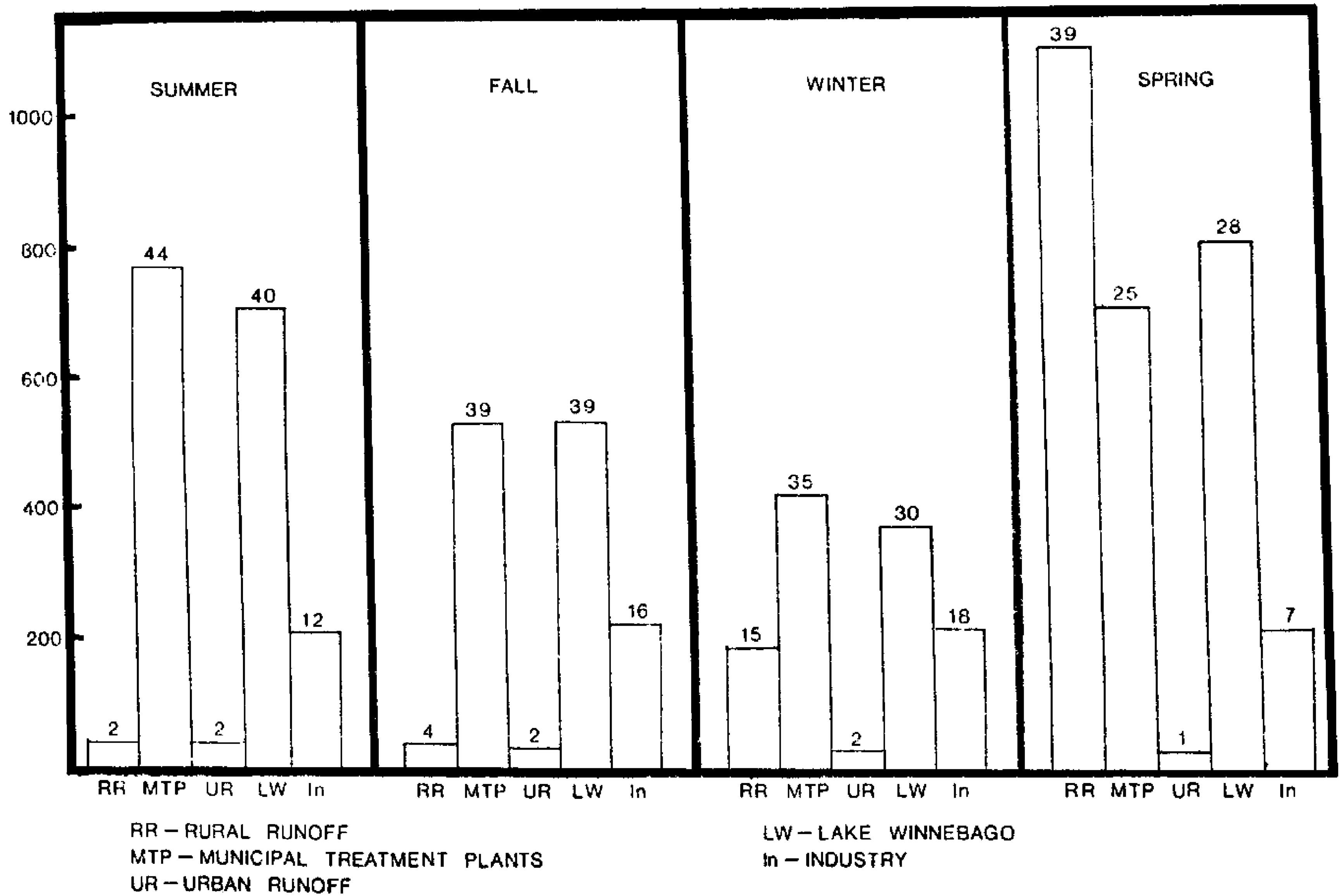

Figure 61. Estimate of Total Phosphate Sources to Lower Green Bay. Note the size of the rural runoff load in the spring. From Sager and Wiersma, "Phosphorus sources for Lower Green Bay, Lake Michigan," Journal Water Pollution Control, Marcy 1975.

decades the focus of the program gradually shifted from the multiple-purpose control of soil erosion to individual farm management for greater economic productivity. . . . Only selected conservation practices promise to be highly profitable under normal market conditions while many involve potential losses.

Few farmers, therefore, are compelled to use land and water so as to minimize the social costs of land erosion and run-off to river basins. . . . Considering the voluntary and fragmented status of agricultural wastes management, this represents a major discrepancy among the principal social institutions generating environmental wastes. This gap in pollution abatement seriously qualifies the national program for improving water quality.[48]

Since erosion control is intimately linked with land use control, a much contested issue, the solution to surface runoff will not be waiting just around the corner.

However, methods are being developed to assure more efficient use of fertilizers and less leaching and runoff of nutrients into surface and ground waters. U.W. soil scientists, for example, have determined the precise nitrogen requirements of potatoes and how and when fertilizer should be applied for maximum growth and minimum fertilizer loss.[49]

The system depends on close adherence to an irrigation-fertilizer schedule. Whether farmers will actually follow such a schedule for nitrogen or any other fertilizer depends largely on how expensive fertilizer becomes. Cost of fertilizer may also be the determining factor which prompts better management of manure. Part of the nutrient and soil run-off problems may be solved when manufactured chemical fertilizers become so expensive that all farm practice revolves around the conservation and maximization of soil nutrients.

At least one trend is currently apparent, however, that may affect nutrient and soil runoff. Throughout the Green Bay region, agriculture which is economically marginal is being abandoned. On the northwestern shore, many impoverished farmlands are being allowed to return to forest, a more efficient use of the nutrient-poor soils. In areas like Door County, however, the benefits of the transition out of agriculture are debatable. Traditionally, the poorest lands in terms of slope and depth of soil over bedrock were put into cherry orchards on the Door Peninsula. Now, in face of severe competition from Michigan fruit growers and rising tax assessments, the orchards are being sold and cleared, largely for second-home development. However, the soil characteristics have not changed; second-home and resort development over the shallow soils may simply alter the nature of the problem from one of marginal orchards to one of sewage disposal and groundwater contamination.[50]

Indirect contributors to Green Bay's problems are the agricultural processing industries of the region (Figures 63 and 64). Stream Pollution in Wisconsin, a report by the State Board of Health in 1927, cited the wastes of meat packing and rendering plants, milk factories, and canneries as being contributors to the pollution of the Lower Fox River.[51] Today, dairy products make up about 50 percent of all farm products produced and sold in the Fox-Wolf watershed.[52] The processing of these products generates wastes with relatively high BOD. However, the canning and freezing of fruits and vegetables has an equally high if not higher BOD--ten times the strength of domestic sewage. These food wastes can be handled in three basic ways: by turning them into marketable by-products, by applying them to the land as fertilizer, by building industry-owned sewage treatment facilities, and by tying into a municipal sewage treatment system.[53] (Often plants that tie into a municipal system are still required to provide their own primary treatment.) Industry that can afford to will generally build its own sewage treatment plant. But when this is not possible, and when a municipal system with the necessary capacity is not available, the processing plant may be forced to shut down.[54] Some small cheese and butter plants have come to this end. For these reasons, strict compliance with water quality standards in the food processing (or the paper pulp) industries is presently balanced against the expected economic loss to the local community and the state as a whole.

S. R. UDELL.
C. F. MURPHY.

[illegible]
F. W. [illegible]

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GREEN BAY, WIS.

CHICAGO.

The growing importance of Green Bay as a distributing center is in no way more forcibly shown than in the anxiety displayed by outside firms to establish in this city branch houses. One of the most recent of these branches is that of Messrs. S. R. Udell & Co., of 33 and 35 South Water street, Chicago, exclusive dealers in cheese, who have opened a store at 129 North Washington street, which is in charge of Mr. J. R. Meyers, a former traveling buyer. The parent house in Chicago has been established for twenty years, and does an immense business over the whole United States in this important product and the firm are finding the Green Bay house a useful feeder to their trade in this state. The premises here measure 30x100 feet and consist of a two-story building, in which a stock of the value of between ten and fifteen thousand [illegible] lars is always carried. The finest grades and [illegible] imported and American cheese are to be obtained [illegible] the stock has continually to be renewed because [illegible] large orders that come in from jobbers in the north, west and east. Mr. Meyers is a native of this state, and [illegible] stands the exact nature of the demand in [illegible] opened his branch in May, 1892, and being [illegible] of the various makes of this table delicacy [illegible] in stock the richest and finest flavored cheese [illegible] kind. The store is only just becoming well known [illegible] in the state, and is certain in the near future [illegible] the center of a large and prosperous business [illegible] under the excellent management of its present [illegible]

Figure 62. From Pen and Sunlight Sketches of the Principle Cities of Wisconsin (Chicago, Illinois: Phoenix Publishing Co., ca. 1894.)

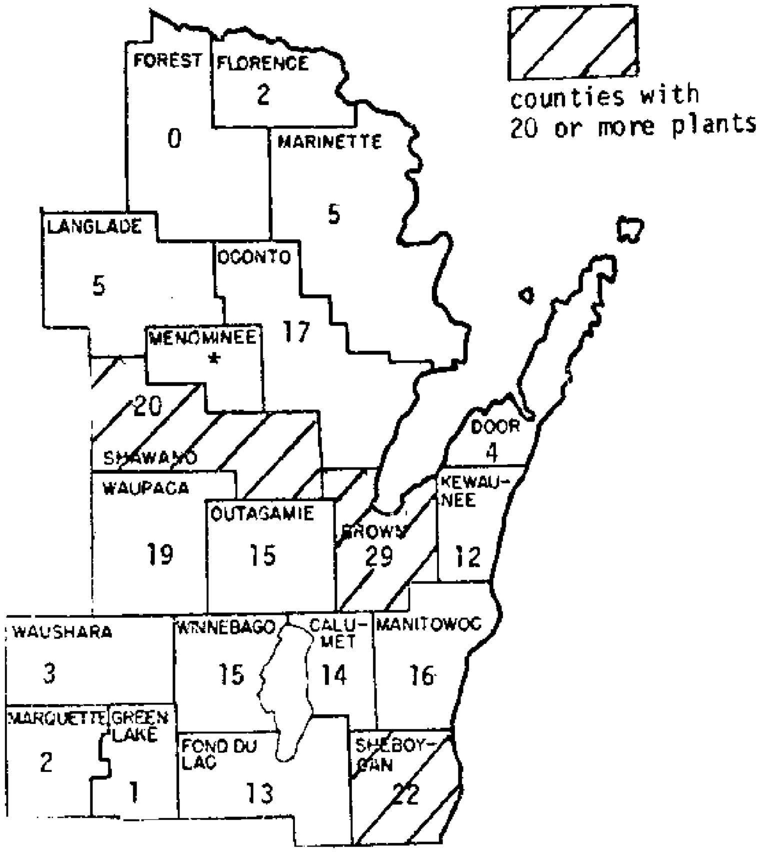
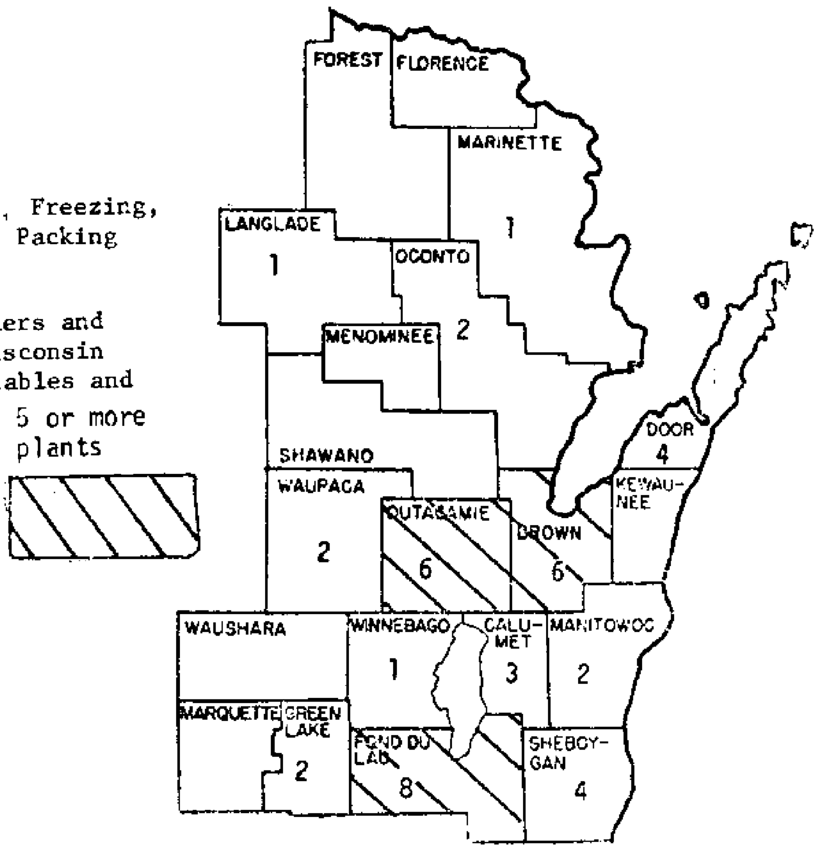


Figure 63. Number of licensed dairy plants by county, 1972.

From Food Division, 1972 Wisconsin Dairy Plant Directory, Madison: Wisconsin Department of Agriculture, 1972.

Figure 64. Canning, Freezing, Pickling, and Kraut Packing Plants, 1972.

From Wisconsin Canners and Freezers Assoc., Wisconsin Processors of Vegetables and Fruits, Madison, Wisconsin, May 1972.



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10. RECREATION

10.1 RECREATION AREAS OF GREEN BAY

The Green Bay area has been a recreation center for the urban dwellers of northeastern Wisconsin and neighboring states since the late 1800s. Door County, especially, has a long history as a resort community. Today recreation is a million dollar business in the Green Bay region and ranks along-side wood products and agriculture as an important industry of the region's northern counties. In 1968, for example, visitors to Door County alone spent $13,164,000. That $13 million, in turn, generated a total sum of $28,619,000 for the area.[1]

However, the economic importance of recreation varies in different portions of the bay's watershed. Table 45 shows the proportion of resort and seasonal accommodations in the northeastern counties as compared to the central and east central counties. Clearly, the northern counties are geared to summer vacation activities while the other regions largely provide temporary accommodation for travelers passing through the area. The northern counties are also primarily seasonal, only 11% of the facilities operating year around. By contrast, approximately 40% of the accommodations in the east central counties are open all year.

TABLE 45

	Northeast	Central	East Central
# all year operations	160	171	175
# seasonal operations	1,246	233	269
Type of Accommodation	Resort 80.7% Hotel 1.6% Motel 8.1%	45.6% 14.9% 30.7%	33.6% 6.7% 33.9%

*Customer Orientation	Vacation	Overnight	Vacation and Overnight
Fishing	76.8%		40.2%
Swimming Boating	59.7%		54.9%
Hunting	8.4%		3.9%

* Main tourist attraction of location

From Fine and Tuttle, "The state of accommodations and their related business activities catering to tourists, vacationers and other transients." Wis. Development Series Vol. II, Nos. 3, 4 and 6, Wis. Department of Resource Development, 1966.

Areas of the Green Bay watershed also vary in their abilities to meet the recreation needs of particular communities or to attract particular kinds of user groups. Door County, for instance, is apparently enjoyed by many for its sightseeing and golf; and the Upper Peninsula of Michigan is popular for sightseeing and camping (see Table 46). These are not, however, featured activities in the west counties of Oconto and Marinette where boating and fishing are favorite diversions.

TABLE 46

OUTDOOR RECREATION ACTIVITY PARTICIPATION
(% of Total Great Lakes Recreation Use)

Counties	% Use By Wisconsin Residents	Largest Non-Wisc. User Group	Swimming	Camping	Sightseeing	Golf	Fishing	Picknicking	Boating
Shawano, Oconto & Marinette	89%	Minn (5%)	3.3	2.9	0.3	1.7	3.8	2.7	3.6
Brown, Door & Kewaunee	69%	Ill (2%)	3.1	3.9	4.4	10.1	2.3	1.5	2.7
Menominee, Delta & Other U.P. Counties	28%	Mich (56%)	3.2	5.6	4.6	3.4	3.4	8.9	3.2

From Upper Great Lakes Regional Recreation Planning Study Part 2: Recreation Demand Survey and Forecasts. 1974. pp. 27-39.

Wisconsin residents are the largest users of all Green Bay recreation resources, while some areas like Marinette, Oconto and Shawano are visited predominantly by Wisconsin residents (Table 46), other areas, notably Door County, have high percentages of out-of-state visitors (Table 46 and Figure 65). Not surprisingly, recreation areas closest to urban centers are generally most heavily used by people from those centers. For example, Marinette and Oconto counties are heavily used by Green Bay residents and the Wolf River area is visited frequently by residents of Oshkosh and Appleton. In their survey of Green Bay recreation users, Ditton and Goodale found that 25% of second-home owners in the bay region came from the city of Green Bay.[2] Similarly, a 1966 survey of Wisconsin second-home owners revealed that 55% of the owners lived within 50 miles of their summer homes or cottages and more than 76% lived within 100 miles of their summer homes.[3] (A more recent survey (1973) suggested that the distance has lengthened somewhat with only 26% of the second homes located within 50 miles of the owners permanent residence.[4])

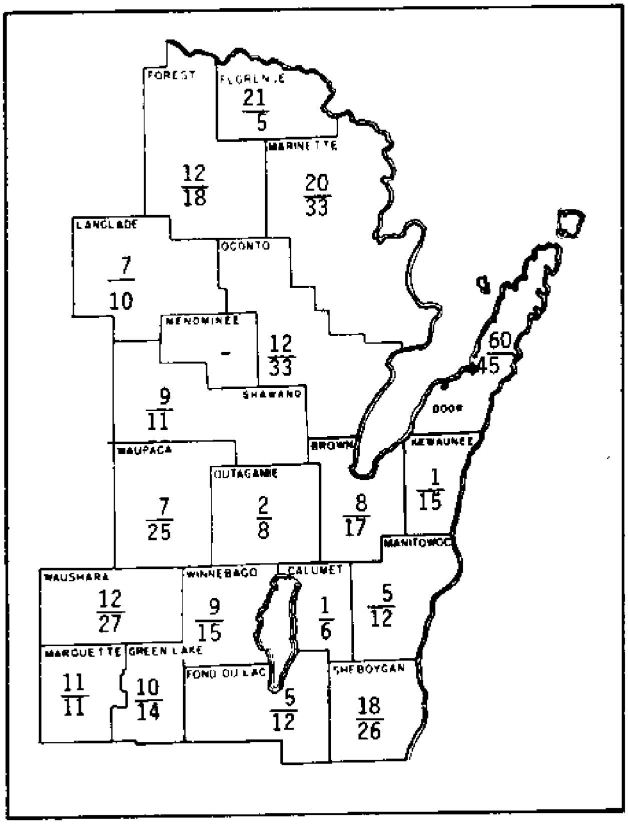


Figure 65. Visits (in 1000s) to Green Bay Counties on an average summer Sunday. The upper number is non-resident visits; the lower number, resident visits.

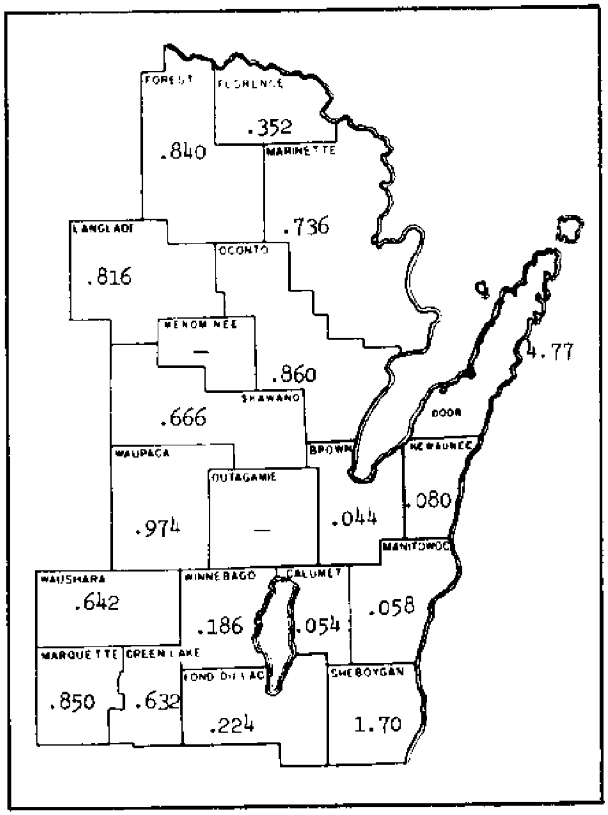


Figure 66. Seasonal commercial overnight housing capacity (in 1,000s of people at 2/room).

From "Wisconsin's Dilemma: Tourists, Good or Bad," Wisconsin Department of Natural Resources, 1974.

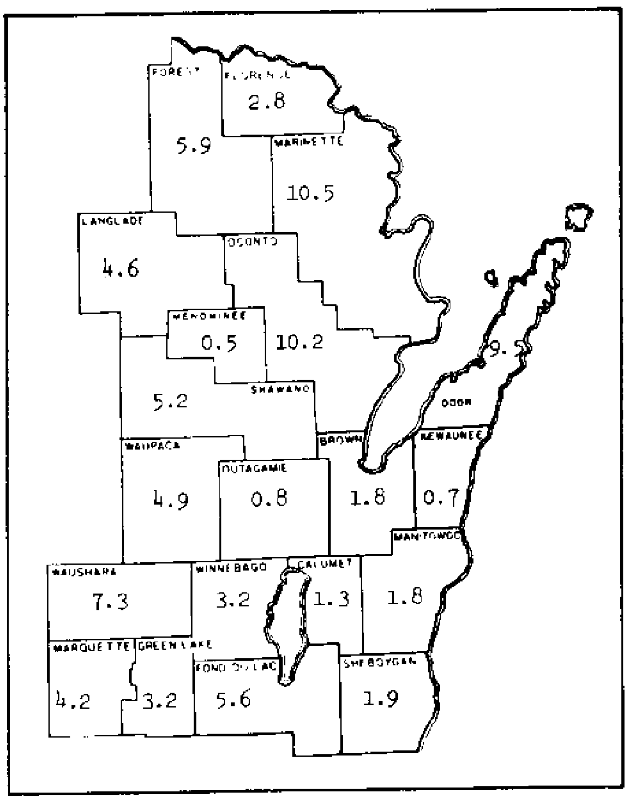


Figure 67. Seasonal homes normal usable capacity (in 1,000s of people).

From "Wisconsin's Dilemma: Tourists, Good or Bad," Wisconsin Department of Natural Resources, 1974.

Proximity to the recreation area is important. But the cost of visiting an area can also determine whether or not that place is chosen for recreation. The cost of vacationing in an area is often a function of its attractiveness and popularity. In the Green Bay region, for example, Door, Marinette and Oconto counties all rank among the top ten Wisconsin counties in terms of private seasonal housing (Figure 67). In 1960, Door County had 4,715 cottages or second homes; Marinette, 2,735; and Oconto, 2,951.[5] Door County not only outstripped the other two counties in numbers of cottages, but also in numbers of hotels and resorts (Figure 66).

Though Door County and Marinette County are about equidistant from the population center of Brown County, Door County is clearly the more popular recreation area. To many people the rocky shores and bluffs of the Door Peninsula are more attractive than the low-lying marshy coastline of the opposite bayshore. Property values are higher in Door County, making recreation there not only more expensive but also more exclusive. Conversely, property values on the Marinette-Oconto counties shore are lower and cottage sites are more available to people with moderate incomes who live nearby.

In 1965-1966, Fine and Tuttle made some comparisons between seasonal homeowners at Lake Shawano in Shawano County and Lake Geneva in Walworth County.[6] Making a bold assumption that Lake Shawano cottage owners are fairly representative of seasonal homeowners in the western Green Bay counties, and that Lake Geneva users have some affinities to the largely metropolitan seasonal residents of Door County, it is interesting to look at the findings (Tables 47-50).

TABLE 47

ONE-WAY DISTANCE FROM PERMANENT HOME TO COTTAGE

Miles	Lake Shawano		Lake Geneva	
0- 25	23.0 %	Green Bay, Fox Valley	4.0%	
26- 50	35.9		16.9	
51- 75	4.0		41.9	Chicago
76-100	1.3		31.1	
101-150	23.9	Madison & Milwaukee Chicago	.7	
151-200	2.2		.0	
201-300	6.2		1.4	
301-400	1.3		.0	
401-500	.0		.0	
501+	2.2		4.0	

From Fine and Tuttle, "Private Seasonal Housing," (1966).

Table 48. Factors in Choice of Cottage Location

	Lake Shawano	Lake Geneva
Swimming	88.0 %	96.9 %
Fishing	93.6	66.3
Hunting	37.8	8.8
Water Skiing	54.9	73.1
Golfing	27.9	54.4
Boating	77.3	84.4
Winter Sports	15.9	38.1
Hiking Nature Study	36.1	41.3

From Fine and Tuttle, "Private Seasonal Housing," (1966).

Table 49. Age of Cottage Owners

Age	Lake Shawano	Lake Geneva
18-24	.9 %	0 %
25-34	3.9	3.1
35-44	23.8	10.6
45-54	31.6	25.6
55-64	20.4	28.1
65+	9.4	32.6

From Fine and Tuttle, "Private Seasonal Housing," (1966).

Table 50. Annual Income of Cottage Owners

Income	Lake Shawano	Lake Geneva
$ < 3,000	11.2 %	0 %
3,000 to 4,999	8.4	3.4
5,000 to 7,499	21.5	2.0
7,500 to 9,999	23.4	.0
10,000 to 14,999	21.5	12.1
15,000 to 19,999	7.0	12.6
20,000+	7.0	69.9

From Fine and Tuttle, "Private Seasonal Housing," (1966).

These figures suggest that the summer homeowner in Shawano County is younger, makes less money, seeks more active outdoor sports and probably lives in the Green Bay City-Fox River Valley area or the Madison-Milwaukee areas.

The income of the vacationer appears to have an important effect on the variety of activities that a recreation area can afford to offer. As one study noted:

> . . . almost 55% (of visitors to Door County) have annual incomes of over $15,000. Thus, they have the discretionary income to support the shops, restaurants and other attractions in the county.[7]

This diversity of entertainment opportunities seems, in turn, to diminish the importance of actually participating in water-based activities. Strang found that although the Door County shore of Green Bay offers generally better water quality than the opposite bayshore, only 16% of Door County visitors came specifically for water-based activities.[8] In Door County, the bay is enjoyed by many simply as part of a refreshing landscape.

10.2 WATER QUALITY AND RECREATION

The availability of water is probably the most important single factor in the selection of recreational housing in Wisconsin,[9] regardless of how intensively the water resource is actually used. A number of years ago, L. G. Monthey showed that resort distribution in Wisconsin was closely correlated with the distribution of named lakes.[10] This relationship certainly holds true for Marinette and Oconto counties where the majority of resorts are on inland lakes and rivers.

Despite the popularity of inland waters, there are almost no resorts on the west shore of Green Bay. While there are many private residences, a number of them seasonal cottages, the west bayshore is not a tourist area. By contrast, in Door County, resorts vie with cottages for a select spot on the bay. There are several reasons for this great disparity in the use of the east and west shores. Besides the fact that it is picturesque and is a traditional vacation area, Door County on the bay's eastern shore, has small bays which are protected, relatively shallow, and closely resemble inland lakes. Secondly, the water quality north of Sturgeon Bay is good. Thirdly, the geology of the Door Peninsula has blessed it with gravelly and sandy beaches.

By contrast, the west shore of the bay has suffered from localized pollution, particularly at the river mouths. And because much of the shoreline is muddy and marshy, it has limited appeal to the swimmer or sunbather. The low ground also presents a somewhat risky building site because of both short-term and long-term fluctuations in the bay's water level (see discussion of shoreline flooding on pp. 109-119). Finally, the shallows in this area are continually wind-stirred, creating fairly turbid water. Though turbidity depends largely on the bottom type and water depth, it is significant that the public commonly associates turbid water with polluted water. In a survey of Wisconsin residents, Elizabeth David found that algal scum and murky dark water were considered first and second in importance, respectively, as indicators of polluted water.[11] This certainly suggests that the waters along much of lower Green Bay's shoreline would not be first choice areas for swimming and beach activities.

Ditton and Goodale, in fact, found this to be true in their investigation of recreation in lower Green Bay. Ditton and Goodale studied the recreational use of the bay by residents of the five surrounding Wisconsin counties—Door, Kewaunee, Marinette, Oconto and Brown. Of the swimmers in the region whom he interviewed, 48% used inland lakes most frequently,[12] and 50% of those preferring inland lakes cited "cleaner water" as the reason for their choice. By contrast, of those who swim in Green Bay primarily, 63% did so because of its proximity. Most of this 63% were from Brown, Oconto and Marinette counties. Only 15% of the bay users participated because of "cleaner water."[13] Of those who swam in the bay, the majority used the beaches midway up the bay.

Ditton and Goodale found that the highest proportion of swimmers were Wisconsin people vacationing in the area. Permanent residents of the bayshore counties, with the exception of those in Door County, used the bay less frequently than visitors.

> Residents of Door County along with seasonal visitors, were more likely to swim in the bay than were other resident groups. Among Green Bay and Brown County residents, inland lakes and pools were more likely used than was the bay, and in Marinette and Oconto, inland lakes and streams and rivers were most popular.[14]

For those who did use the bay for swimming, the troublesome features—aside from bad smell and dead fish—were wind, coldness, waves, and turbidity ("cloudiness") of the water.[15] It is not uncommon to hear residents of the area describe the bay as "rough," "treacherous," or "dangerous." These physical features of the bay, and its susceptibility to sudden storms, are things which remain unaffected by pollution cleanup.[16] This should be kept in mind when developing recreation plans for the bay.

People who won't swim in the bay are not as particular when it comes to fishing in the bay. Fishermen are more tolerant of less-than-perfect water quality since eutrophication can often improve fishing success. Ditton and Goodale found that Green Bay was fished almost as frequently as inland lakes and streams, and that the main reasons for fishing the bay was its proximity and good fish catch.[17]

Eighty-seven percent of those fishing in Region I (see Figure 68) were from Brown County and Green Bay City. Eight percent of Region II users were from Green Bay City, Brown and Oconto Counties. Region III fishermen were 34% from Door County and 26% from Green Bay City. Marinette County residents made up 59% of those fishing Region IV. Region V (in Michigan waters) was fished by only 20 fishermen, 12% whom lived in the city of Green Bay.[18]

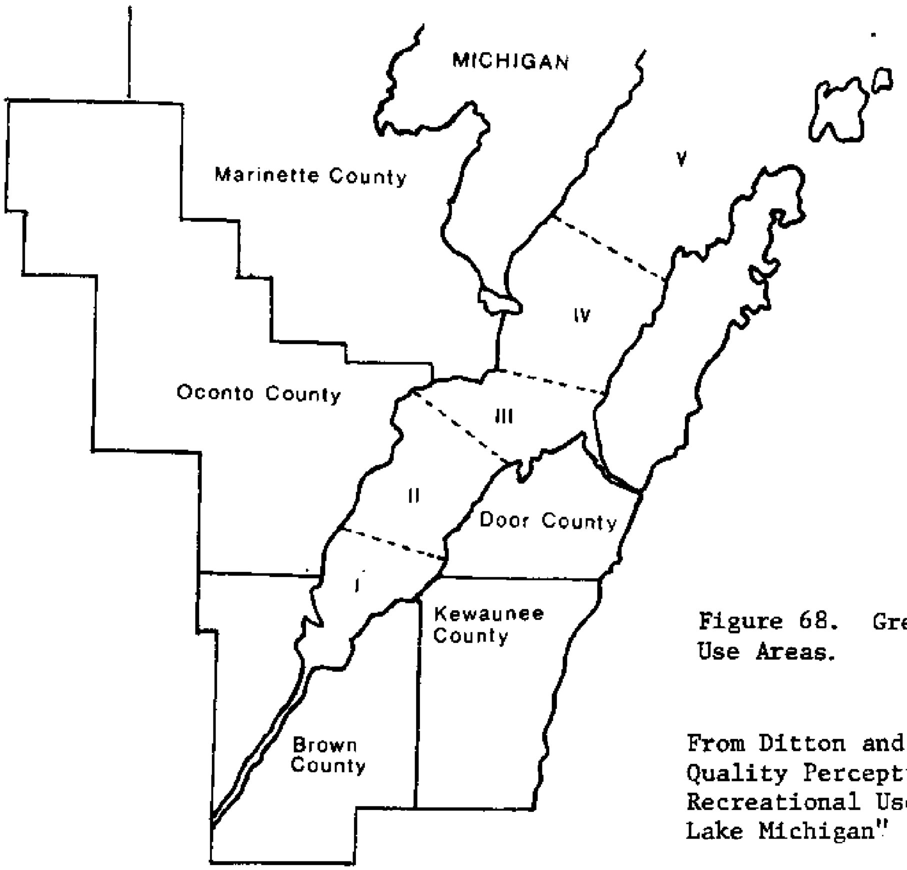


Figure 68. Green Bay Recreation Use Areas.

From Ditton and Goodale, "Water Quality Perception and the Recreational Uses of Green Bay, Lake Michigan" (1973)

Since fishermen go where the catch is good, one must assume that if improved water quality also improves fishing, Green Bay will be more heavily fished. Boaters, however, view their activity as one that can be carried on extensively regardless of water quality. Though Green Bay could accommodate many boats, it is largely unused. Part of the reason is the greater popularity of inland lakes. Marinette and Oconto County lakes and streams are especially popular and are fished twice as often as the bay by local fishermen.[19] However, lack of launch facilities and harbors of refuge are also important reasons for the bay's relative disuse. In the city of Green Bay, there are only two public boat launching areas. And throughout the rest of the bay, facilities are severely limited. Access has deteriorated historically to the point where today access is almost nonexistent.[20]

The importance of public boat access as a means of increasing use of the bay is demonstrated by the situation in Grand Traverse Bay, Michigan. Grand Traverse, which is a bay about the size of lower Green Bay, has 12 public launching sites in addition to private facilities.

> In terms of angler activity, boat fishing originating at public launching sites was the most important source of fishing activity on Grand Traverse Bay.[21]

10.3 THE RECREATION BUSINESS

In spite of its overall economic importance to the region, the recreation industry in northern Wisconsin includes a number of marginal operations in which profits are often small and vary considerably from year to year. While resorts, motels, campgrounds, restaurants and amusements are the immediate recipients of the recreation dollar, their receipts are seasonal and dispersed among a number of people with no one getting a very big part.

In the early 1960s, the Wisconsin Department of Resource Development conducted a series of studies on Wisconsin's recreation industry, considering particularly the status of the resort sector. Throughout the state, the investigators, Fine and Tuttle, found small resort operations (1-4 room units) in a very unstable condition

> Entrance into the business is relatively easy since only limited capital is required. The limited capital, unfortunately, often assures that exits may also be rapid but painful. This category of operation cannot provide even a modest annual income to the owner. . . . There is also a growing awareness on the part of potential owners that a 1-4 room operation will not provide an adequate level of income and thus the number of new establishments in this category will be minimal.[22]

Fine and Tuttle predicted that by 1980 the greatest growth of accommodations would be in the 31 room and up category. They deemed this a positive change since larger establishments provide more employment opportunities to local residents than the smaller operations. In fact, a follow-up survey, by the UW Recreation Resources Center (1974) showed that between 1971 and 1974 there was a 20% decline in the number of 1-4 room facilities in the Green Bay and Lake Winnebago regions.[23] This was a loss of 103 small establishments. Simultaneously there was an increase of 9% and 10% respectively in the number of motels and hotels with 31 or more rooms. This trend to large establishments with more rooms meant an overall 5% increase in overnight accommodations, but a total decrease of 8% in the number of hotels and motels.[24]

That the smaller businesses often have difficulties making ends meet was clearly demonstrated by Fine and Tuttle. In an examination of the northeastern counties of Wisconsin, including Florence, Forest, Marinette and Oconto counties, Fine and Tuttle found that 38% of the small "ma and pa resorts" were operating at a financial loss and only 25% were earning over $2,500 net.[25] Fine and Tuttle also found that almost 30% of these resorts also operated a bar or tavern (see Table 51). Over 50% of the resorts with bars depended on them heavily for at least half of their gross income. In addition, 83% of the owners felt it was necessary to offer boat rental facilities even though boat rentals generally provided less than 10% of the resorts income.[26]

Fine and Tuttle found most small resort owners limited in their efforts to upgrade their businesses by a lack of capital for property improvement or facility expansion. That improvement or modernization was needed was evidenced by the fact that many of the buildings were at least 30 years old. As Fine and Tuttle so aptly put it:

Table 51. Comparison of Small Resorts in Northeastern and East Central Wisconsin

	Northeast	East Central
Ownership by operator	97%	96%
Average size of lodging unit	8.4 units*	12.2 units***
Number of operations providing owner 91% of income	52.1%	47.6%
Percent operating at a loss	38.1%	12.5%
Percent operating at profit in excess of $7,500	6.2%	17.7%
Facilities operated in conjunction with bar or tavern	ca 28.0%	ca 26.0%
Facilities in which tavern provides over 50% of gross income	55.0%	25.0%
Facilities operated in conjunction with restaurant	ca 22.0%	ca 35.0%
Facilities with boat rentals	83.0%	48.0%
% Boat rentals providing only 1-10% of income	86.0%	70.0%
# Operators depending solely on family for labor	23.0%	9.0%
Percent using family member to keep books	94.0%	86.3%
% of facilities at least 18 years old in 1962	54.6%	45.2%

* 60% were 7 or less
** 47% were 7 or less
*** 37.5% were 7 or less

From Fine and Tuttle, "The state of accommodations and their related business activities catering to tourists, vacationers and other transients," Wis. Development Series, Vol. II, Nos. 3, 4 and 6, Wis. Department of Resource Development, 1966.

The vacation-recreation industry in Wisconsin is an old industry - with a history dating back to before the turn of the century. Unfortunately, some of the accommodations available to the visitor also date back as far.[27]

The main source for the financing of business improvements are banks. However, "the extremely short season and the transitory nature of the customer in the industry does not make it particularly attractive to normal sources of risk capital.... Lack of adequate financing appears to be a major hindrance to adequate modernization of this industry..."[28]

Lack of modern facilities continues to be a hindrance to the recreation industry and money for improvements certainly has not become any more accessible.

The apparently marginal nature of much of the tourist trade in northeastern Wisconsin, as suggested by the low income and poor prospects for business expansion, makes one wonder why these establishments continue to operate. Part of the answer is that more than half of the owners have retirement income or hold second jobs.[29] But an equally important reason is that many people in the recreation business get the same kind of "psychic income" that Strang and Ditton found charter boat operators often sought from their businesses.

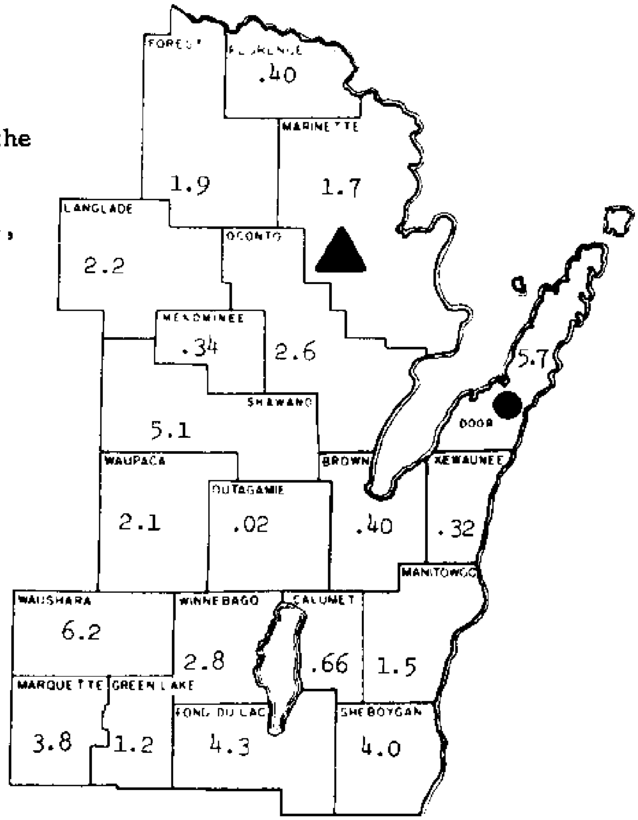
Although one might question how long this psychic income will offset the economic opportunity costs to the operators, it has been recognized that many northern Wisconsin resort operators have continued to operate their businesses for similar reasons and with similar results for decades.[30]

It is significant that almost all resort operators surveyed by Fine and Tuttle were also the owners of their establishments and were "their own bosses" (see Table 51).

In recent years all recreation areas have seen a new kind of tourist, the camper, and a new recreation business, the private campground. The increased popularity of camping that began in the 1960s was not well received by resort owners. Not only did the owners feel they were losing business to both public and private campgrounds, but they objected to increased numbers of campers congesting the public facilities of resort areas.[31] This was especially true of Door County which has three state campgrounds, and the highest overnight camping capacity in the region (see Figure 69).

Residents and seasonal cottage owners in many areas are adamant that there should be no further construction of public recreation facilities because of over crowding.[32] The cottage owner especially feels strongly. He often comes from out-of-state but pays property taxes in Wisconsin; he feels he has made a greater sacrifice for his use of the area; and generally coming from a metropolitan area, he feels entitled to claim the exclusivity he has purchased and to exclude the rest of the public as much as possible.

Figure 69. Campground capacity in the Green Bay Region. An approximation in 1000s of campers/county. From "Wisconsin's Dilemna: Tourists, Good or Bad," Wis. Dept. of Natural Resources, 1974.



Over 50,000 Visits to DNR Campgrounds/Summer Day

▲ -- Residents Predominate

● -- Non-residents Predominate

Resort owners are more selective in their discrimination. They encourage the weekend or two-week visitor—as long as he doesn't camp.

The financial rewards of operating a campground, like those of a small resort, are marginal. Most campground operators, unless they have at least 100 camp sites, must also depend on other sources of income.[33]

10.4 FUTURE RECREATION ON GREEN BAY

> . . . it is abundantly clear that the major reason Green Bay is a primary location for (recreation) activity is proximity. In comparison, for those using inland lakes primarily, proximity appears to be much less important a reason. The attractions of inland lakes seem to be sufficient to overcome longer distances, if one considers that most of the population lives close to the bay . . . .
>
> Ditton and Goodale, "Marine Recreational Uses of Green Bay," 1972, p. 75.

The people of the Green Bay region have become disenchanted with their bay. As water quality in the bay deteriorated over the years, there was less interest in providing boating facilities or bathing beaches. By the time that sewage and industrial contamination had been controlled, the automobile had made inland lakes accessible and swimming pools had become fairly common. By comparison, the bay looked rough, murky and dirty. From conversation with area residents, it is apparent that many of them now see the bay as a boundary line rather than a resource. While a large-scale reversal of this attitude is unlikely, there are signs of renewed interest in the bay in those places where water quality is locally improved.[34] There are also signs that rising prices of gasoline (and inflation in general) will force people to seek recreation closer to home.

On the other hand, if water quality further deteriorates, use of the bay by sport fishermen and swimmers can be expected to decline. Ditton and Goodale in surveying Green Bay fishermen found that many intended to fish elsewhere if water quality got any worse.[35] This potential dislocation of the sport fisherman could have serious implications.

> . . . the avid Lake Michigan fishermen also boated, duck hunted and picnicked at Lake Michigan sites . . . . This strongly suggests that if one activity is dislocated, the other activities will also be dislocated.[36]

Similarly, there is a high probability that swimmers who decided to swim elsewhere would also relocate their swimming and boating activities to a non-bay site. According to Ditton and Goodale, "dislocation of all uses appears to occur when the least tolerant use is dislocated."[37]

The economic impact of a disaffection of recreation users on Green Bay and Lake Michigan was estimated by Strang in 1970. He calculated that if deteriorated water quality caused a 50% decline in tourist trade, Door County would suffer an annual loss of $14,000,000.[38]

In this light it is important that pollution abatement efforts be pursued vigorously. It is also important that people be encouraged to use the bay as it improves and that facilities be ready for them when they arrive.

> Without facilities, it is difficult to rekindle a demand which has been dormant but shows signs of re-awakening. . . . Without access and facilities (particularly for boating), water quality improvement benefits associated with recreation use may be markedly reduced.[39]

The problems of turbidity and rough water are relatively strong deterrents to body contact recreation in Green Bay and are likely to remain so. For these reasons, recreational planning and facilities probably should not focus on swimming as a significant use of the bay, or at least of the lower bay. However, boating and fishing are activities that would benefit from increased attention. There is a shortage of not only adequate launching facilities but also marinas and boat storage areas in the lower Green Bay area.[40] It has been suggested that an increase in harbors of refuge might increase the boating use of Green Bay. However, Wisconsin presently has very little money allocated for this use. One proposed solution is to follow the Michigan system of diverting taxes paid on motorboat fuel to the construction of harbors of refuge.[41] Possible sites for improved boating facilities in the lower bay are the Pensaukee, Big Suamico and Oconto harbors. These waterfront areas all occur within a couple of hours drive of Green Bay City. If marina or launching facilities were combined with attractive restaurants or shops, these places could become destinations in and of themselves.

Other attractions might be developed around the west shore's natural features: its wetlands and its historic heritage of fishing and lumbering. The marshes along Green Bay have a diversity of bird life that is unmatched in most other areas of the state. A nature-information center and a carefully designed network of boardwalks in one of the state-owned refuges could enhance the recreational offering of the lower bay area. Such an area might draw sufficient visitors to provide patronage to nearby eating places, particularly if the restaurants or other businesses stressed the rather colorful history of the region in their decor.

It has been suggested by some that development of tourist facilities on the middle and northern portions of Green Bay's west shore might be aided by a ferry connection between Door County and Marinette. The Washington Island ferry is very popular with Door County visitors even though Washington Island has a limited number of attractions. The economic feasibility of a trans-Green Bay ferry might merit serious study.

When a region, such as the western shore of Green Bay, lacks conspicuous natural attractions, a fair amount of capital, careful planning and extensive promotion are often needed to draw in visitors. One successful method is for several businesses — one or more restaurants and a motel or two — to form a "recreational complex."[42] The businesses advertise together, promote use of one another's facilities and sometimes offer a single price package. Careful planning is especially needed if the complex is to complement and not detract from the region's prime recreation features, whether it be a wetland nature center or a historically renovated waterfront area. Motorboat rentals, for example, adjacent to a bird watching area would be not only incompatible, but destructive. Canoe rentals, however, in a protected water area, could be quite compatible with game refuge goals. Similarly, historic renovation requires a careful blending of the old with the new in order to maintain compatibility.[43]

While the forementioned type of recreation complex is a means of developing a recreation area without large amounts of capital, it is also a difficult arrangement to realize. Small businessmen are very independent and are often reluctant to cooperate in such a venture.[44]

Currently the recreation services of the bay shore counties, except Door County, revolve primarily around the second homeowner. Marinette and Oconto counties have been especially popular areas for seasonal homes since the 1940s. Indeed, over the last ten years, many of the region's small resort owners have sold off their rental cottages as second homes.[45] However, questions have been raised recently as to the wisdom of encouraging further second home development. Although cottage owners pay property taxes, they are also very demanding in terms of county and town services.[46]

In addition, the second homeowner brings limited revenue to the area except for his taxes. He does not patronize motels or restaurants nor is he in residence for a very large part of the year. The tourist, on the other hand, patronizes the local businesses exclusively during his visit. And when he leaves, his place is filled by another tourist. The resort cottage compared to the second home cottage, has a tenant throughout the season.

If it is desirable to promote tourism rather than second home development, it may be essential that the bay shore counties increase the diversity of their recreation offerings. Moreover, any attempts to increase recreation use of the west shore area should be preceded by a strict shoreline zoning program. In the Green Bay region, as in other coastal areas of the Great Lakes, the land most likely to be developed is usually the most fragile land from an ecological standpoint.

> ... land with development potential is often located on water frontage. Such land is often low, wetland or of very steep slope or of unstable soils such as the red clay cliffs.[47]

This is certainly true of the west shore where ground water lies just below the sandy soils and is easily exposed by development, and where flooding due to high bay waters is not uncommon. Similarly, the eastern shore has a sensitive ground water problem though for different reasons. In Door County, the limestone bedrock lies beneath a thin mantle of soil. As a result, septic effluent often seeps through fractures into the ground water without receiving adequate soil filtration.[48]

Regardless of these problems, shoreline development appears to be proceeding all around the bay (see discussion on pp. 265-272). positive or negative point is uncertain, but the more recent construction in many areas is of generally better quality than past seasonal housing.

In Door County recreation development is being actively promoted. The concern that was aroused several years ago by groundwater contamination has diminished, at least temporarily.[49] Yet it will be a real challenge to Door County to endure more intensive recreation pressure and still retain its attractiveness. The charm of Door County lies largely in its landscape — its cherry orchards, farmsteads, and fishing shanties. Unfortunately, these scenic features are too frequently dismantled in the process of building new resorts, second homes or marinas.

The recreation potential of the Green Bay shoreline, and the attendant problems of its development, have recently received the attention of both the state and the university. Besides Sea Grant's studies on the economic impact of small boat harbors, there is also a shoreland inventory in progress under the direction of the state DNR, DOA, and the UW Recreation Resources Center. This project includes a description of existing public and private recreation facilities in Wisconsin's 16 coastal counties, as well as an assessment of the current supply and demand for coastal recreation.[50] The study also aims to assess the economic impact of coastal recreation — both the regional and local costs and benefits.

The Critical Resources Information Program (CRIP) has made some general evaluations of the value of Oconto Connty coastal lands for recreation use.[51]

UW-Extension and the Department of Regional Analysis at UW-Green Bay have recently undertaken a study of alternative land use possibilities on Green Bay's west shore. The work so far, under the direction of James Murray, has been a pilot study of a 2-1/2 mile strip of Oconto County shore (Geano Beach). This study has included an inventory of all natural and socioeconomic characteristics of the area.

The information gathered by all of these studies should be directly applicable to future plans for public acquisition of parkland or shore access points. At present 34% of Wisconsin's Green Bay west shore and 52% of its east shore are in private residential holdings.[52] On the Upper Peninsular 33% of the shoreline is residential.[53] And of those shore areas in public land, a significant portion is either marsh, swamp forest or sheer cliff, all of limited recreational use. Residential development is expected to continue along Green Bay's shore. This is true for the flood-prone west shore as well as the east. Although high waters have discouraged many builders in this area, others have proven willing to meet the extra expenses of living on the rather soggy shore — building above-ground septic systems, landfilling their properties, and raising their foundations.[54] Because of this continuing private demand for shoreline sites, recreation planning should not be delayed. The present high water period has provided a respite from aggressive land speculation on the bayshore and offers cities and counties the opportunity to move ahead with zoning regulation and acquisition plans.

Presently both inflation and recession are taking their tolls on the recreation industry throughout northern Wisconsin. With an increase in unemployment, a decrease in discretionary income and spending power, there has been a growing uncertainty among families as to what future vacations will entail. At the same time, recreation operators have experienced rising costs in providing their services.[55] Compounding these problems are rising gasoline prices. It is expected that as costs of traveling continue to rise, recreation trips to more remote areas will drop off. The rationing years of World War II showed that when fuel is scarce, travel declines dramatically.[56] A Wisconsin survey taken in the midst of the 1974 energy shortage revealed that people anticipated taking fewer trips, taking trips of shorter distances, and staying longer in one place. The prospects for mass transit or rail replacing the private auto in vacation plans are not currently very bright.

These factors make it all the more important that recreation potential in the areas surrounding the city of Green Bay and the Fox Valley be utilized efficiently. And considering the fragile nature of much of the coastal land in this area, it is imperative that recreation facilities be developed with foresight and concern for the environmental impacts.

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11. SHIPPING

11.1 EARLY HISTORY

Green Bay and points along the Fox River have been ports of call for hundreds of years. In the eighteenth century, French fur traders from Canada passed through the Fox Valley and into the depths of the Midwest. By the 1820s, the fur supply in the region had been depleted,[1] but Green Bay waterways continued to shuttle settlers and traders inland to Wisconsin.

As settlers began to take up lands in the Green Bay region itself, merchants and manufacturers saw the benefits to be gained from controlling the Fox River. River improvements, consisting of locks and dams, had two purposes: to eliminate the falls and rapids and make the river navigable; and to harness the river's power for manufacturing. The initial plan was ambitious. It aimed at constructing a complete canal system from Green Bay to the Wisconsin River at Portage.[2] This canal would link the Great Lakes with the Mississippi River and would enable farmers to move their surplus produce from the interior to the eastern states entirely by water.[3]

The plan seemed to hold promise. Marshy reaches of the two rivers passed within one and a half miles of each other at Portage.[4] However, the project was ill-fated. Improvements were made on the lower Fox and some work was done on the upper. But there were too many irregularities in both the visitations of merchant ships from eastern ports and in the flow of the river.[5]

> The opening of the lower Fox to through traffic in June of 1856 failed to solve the transportation problems of Neenah, Menasha (major flour exporting cities at that time). The dry summer which followed ... demonstrated all too vividly the inadequacies of water transportation.[6]

In 1872 the federal government took over the improvement project and revived hopes for a connection to the Wisconsin River.[7] But these hopes were short-lived. Although a shallow draft vessel could traverse the "portage" in times of high water, the canal was inadequate. By 1876 engineers had concluded that making the upper Fox navigable would involve expensive channel walls and extensive improvements in the upper Mississippi.[8] Moreover, by this time railroads had reached into the Green Bay region and found ready customers among the farmers. In 1875 Green Bay had three competing railroads, two more under construction and three in the planning stages, "... all of which, when completed, will give this great centre some nine roads."[9]

By the 1880s, the idea of a connecting river canal had been abandoned, "... though it periodically was re-proposed right up until the 1950s when it was suggested that the St. Lawrence Seaway might revive the importance of the Fox-Wisconsin waterway."[10]

The farmers had found the solution to their transportation problems in the railroads. The lumber industry, however, continued to rely heavily on sail and steamship to move their millions of pine boards and shingles to Chicago and Milwaukee.[11] In 1870, over 7,000 vessels entered Green Bay[12] most of them undoubtedly involved in lumber trade. There were lake schooners and scow schooners, uniquely designed for lumber and grain transport between the lake's narrow harbors, and there were stream tugs and early steam ships.[13]

It was during the lumber boom that the Sturgeon Bay Canal was cut through the Door Peninsula to shorten the trip between Green Bay and the main lake. The passage around Death's Door at the mouth of the bay was not only treacherous but added a hundred miles on to the trip from Green Bay to Chicago.[14] Efforts to build the canal began in 1866 and culminated in the merging of bay and lake waters in 1882.[15]

As long as the timber regions were close to rivers and the buoyant pine logs could be floated downstream, ship transport remained important to the lumber industry. But as the virgin pine tracts became more remote and hemlock and hardwoods made up increasing amounts of the forest harvest, lumbermen, too, adopted the railroad for transport of their logs to the mill and their sawn lumber to market.[16]

In the midst of the lumber boom, a new resource began to flow into Green Bay for processing. It was iron ore mined in the Penokee-Gogebic and Menominee ranges of northern Wisconsin and Michigan.[17] Loaded into railroad cars and gliding the long downhill track to Escanaba, the ore was transferred there to steam barges.[18] Most of the ore was smelted in Ashland or shipped to eastern smelters, but some of it was conveyed down the bay to foundries and blast furnaces setting up along the Fox River. In 1870 a promoter of Brown County wrote:

> The principal seat of this industry is now at DePere ... accessible to the largest vessels and possessed of a splendid water power. ... There are now two furnaces in operation at this place while another is being erected at Green Bay.[19]

Local woodlots supplied the wood for charcoal, an item "which the furnaces consume in enormous quantities." The writer optimistically concluded that since the "inexhaustible" mines of Lake Superior were well connected with Green Bay by rail and steamer, Green Bay could not be surpassed as a smelting center.

> The business of blasting (smelting) is carried on very extensively in the vicinity of the mines, but ... a furnace can be operated here at a cost $50 per day *less than* at the mines. Add to this that the iron when manufactured is 175 miles nearer to the markets of the world and at the best point of distribution in the West.[20]

The blast furnaces did bring important metal working industries to the lower Fox. In 1880, the valley boasted boiler and sheet iron makers as well as manufacturers of bolts, shafts, locomotive axles and threshing machines. That same year Green Bay received shipments of 37,633 tons of iron ore.[21] But neither Green Bay nor DePere became smelter towns. Wisconsin's high grade iron mines were exhaustible and the state did not have the coal resources for large-scale smelting that Pennsylvania and Ohio had. Green Bay harbor still receives pig iron for its Fox Valley iron and steel foundries, but the 10.5 million tons of iron ore shipped from Escanaba in 1972[22] had destinations other than Green Bay and the Fox Valley.

Besides lumber and iron ore, the Green Bay region also produced limestone blocks that required water transport to their destinations. As early as 1834, limestone blocks from the quarries of Sturgeon Bay were being used for pier and breakwater construction.[23]

> The fact that this stone is quarried on the shores of the bay and loaded directly into barges, then unloaded where needed around the several harbors, made railroad competition impossible. ... rarely are stones of the necessary size found elsewhere adjacent to navigable waters.[24]

For many years Door County quarries almost had a monopoly on harbor construction materials. Another construction material exported from Green Bay was bricks. Around the turn of the century, brickyards along the Fox and East Rivers shipped millions of red and cream colored bricks to urban centers,[25] many of them moving by boat.

Besides the stream of barges, steam tugs and lakers that carried bulk products to and from Green Bay ports, there was a constant traffic of small schooners that were the "motor trucks" of their day:

> There were hundreds of them and lists of their cargoes included most rural products and most of the things that were needed by little communities along the lake shores: salted fish, grain, rope, fence posts, pork, coal, shingles, salt, bricks, butter and livestock.[26]

These little ships were essential to the fishing and lumbering towns scattered along the edges of the northern bay. The schooners and tugs continued to serve these communities until World War I when the truck became a practical mode of transport.[27]

It was not long afterward that all goods, except those of great bulk, were moving by rail or truck. Small harbors on Green Bay that had begun to decline with the slumping pine lumber industry, rapidly lost almost all their commercial importance. As of 1972, Pensaukee's commercial trade was 2,943 tons of fish. Oconto shipped 1,401 tons of fish while neither Big Suamico nor Peshtigo had any commercial trade.[28] Similarly, by 1951 commercial shipping on the upper Fox had essentially ceased and the locks were sealed.[29]

Escanaba, Michigan, continues to export iron ore and fish and has the highest tonnage of any Green Bay port. Gladstone harbor on Little Bay de Noc imports primarily petroleum products. Menominee-Marinette harbor exports fish and pulp and receives coal and limestone.[30]

11.2 GREEN BAY AND THE ST. LAWRENCE SEAWAY

Between 1951 and 1958, the Port of Green Bay's commercial tonnage annually ranged between three and three and a half million tons.[31] Then, as now, the major portion of the tonnage was domestic bulk imports of coal; petroleum products; paper pulp; salts; limestone; sand, gravel and crushed rock; clay products and pig iron.

With the opening of the St. Lawrence Seaway in 1959, Green Bay had an increased access to international markets. Although total tonnage did not increase significantly, the proportion of general overseas cargoes rose by 30,000 to 40,000 tons. Besides receiving foreign goods, Green Bay was able to increase exports of grain and processed foods from the Fox Valley.[32] While this increase was only a fraction of the port's total tonnage, it had a significant impact on Green Bay's economy. Foreign cargoes which are commonly general cargoes, consist of numerous different items which require individual handling. Because of the employment it generates, general cargo is actively sought.[33]

Despite the gain in overseas general cargoes, domestic lakewise tonnage at Green Bay declined after 1961. This was due largely to the construction of an oil pipeline from Chicago to Green Bay. Whereas deliveries of oil by tanker to Green Bay were slightly over a million tons in 1961, tanker delivery amounted to only 323,000 tons in 1962.[34] Since 1961, total tonnage of all kinds at Green Bay has not exceeded three million tons.[35] Shipment of petroleum by ship from Duluth to Green Bay now accounts for only 10% of oil coming into the region. About 90% comes by pipeline from Chicago. In fact, the Wisconsin Emergency Energy Planning Office expects that the amount of oil moving by ship from Lake Superior will decrease if the Canadians continue to restrict their exports of oil.[36]

By the late 1960s, there was growing concern over loss of ship traffic at Green Bay. Several reasons for the decline were offered:

1. The Port of Green Bay lies too far off the main lake,
2. The port rarely enjoys a shipping season of more than eight months a year,
3. The port suffers from an absence of modern shipping services and dockside facilities to handle larger ships and containerized ships,
4. Liners using the St. Lawrence Seaway must limit their ports of call in order to realize full economies.[37]

These factors have relegated Green Bay to the status of a secondary "port of inducement." Green Bay is not alone in this category. A number of other Great Lake ports must also continually induce traffic to come their way. A criticism leveled by Seaway authorities is that the ports do not promote themselves adequately. As one observer put it, the Seaway is "essentially neutral. It does nothing for anyone; it merely holds out latent opportunities...." Few secondary lake ports have responded to the Seaway with decisive aggressiveness. An exception is Toledo, Ohio, whose businessmen and city offices launched a concentrated campaign to entice ships to its port and persuade farmers to ship their grain through the Seaway.[38]

11.3 FUTURE PROSPECTS

Where its port is concerned, Green Bay has been plagued by indecision. After years of planning, it has obtained a site for its Bay Port industrial park and harbor facility. It is located right on the bay, west of the Fox River. However, Bay Port is currently viewed as an industrial center foremost. Only 20 percent of the development now scheduled for the area is marine-oriented. The remainder is land-based industry. Plans for a major port facility on the site are in a reserve status and will be implemented only when the existing dock area available in the Fox River channel is being used to full capacity. To what extent a completed Bay Port with expanded harbor facilities would eventually increase Green Bay's shipping commerce is unknown.

Bay Port was initially conceived as a center for general industry and warehousing, both activities being oriented toward the general cargo trade. However, it now appears that the opportunities for increasing Green Bay's general overseas cargo traffic are few. The long winter season remains a problem. The shallow waters of the bay freeze over solidly for several months. Besides this obstacle, there are drifting ice conditions on the main lake throughout the winter.[39] The feasibility of extending the shipping season in Green Bay by dispersing the ice formation has been examined in detail.[40] However, it appears that the open water season can be extended by only a few weeks and at considerable cost.[41]

But whether the shipping season can be prolonged or whether dock facilities can be modernized will not matter if the Seaway locks cannot accomodate the "superships" which are appearing in increasing numbers. The size of the locks is now a major obstacle to greater commerce through the Seaway.

Experts do not now foresee any increase in general cargo movement, although an upswing in lakewise bulk cargoes is anticipated.[42] As a case in point, the port of Superior on Lake Superior is currently building a $10 million coal terminal with the intent of becoming a major receiving and distribution center for western coal. It is also expected that future ship traffic on the Great Lakes will be funneled to a limited number of regional ports that will be considerably improved and modernized.[43] In the Lake Michigan area, Milwaukee and Chicago are prime candidates as regional centers. This will undoubtedly mean a decline in traffic for Green Bay and other secondary ports.

11.4 ENVIRONMENTAL IMPACT

Probably the major impact on the bay system from current shipping traffic is turbidity. The passage of a large ship through the water re-suspends sediments, including polluted sediments, in the immediate vicinity. The stirring of sediments is damaging to benthic organisms and to fish eggs which may be smothered by the shifting substrate. Propeller vibrations are also suspected of damaging some animals. In Green Bay such effects are probably insignificant since the impacts would be confined to ship channels and harbors, areas relatively devoid of life because of dredging activity. In addition to increased turbidity, ships can also create damaging waves in their wake. But again these waves are largely dissipated by the time they reach the Green Bay shore. Perhaps more damage to shoreline and waterfowl habitat is caused by the wakes of powerboats passing close to the shore.

It has been said that a busy harbor is a dirty harbor. Whether one can have a high rate of ship traffic and still prevent accidental spills of materials into the water, illegal pumping of bilges, and seepage of harmful materials into the bay from dockside storage areas is uncertain. By its very nature, the bulk movement of goods is an untidy business. However, the limited amount of traffic in Green Bay and the fact that it is dispersed among the harbors of Green Bay City, Escanaba, Gladstone and Menominee, appear to have kept the environmental impacts of shipping to a minimum. With future shipping trends as they are, this does not appear to be a major environmental problem.

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12. POPULATION AND LAND USE TRENDS

12.1 POPULATION GROWTH

The Green Bay watershed includes both sparsely populated forest areas and heavily populated urban-agricultural areas. The largest center of population is the Fox-Wolf Valley. This area contains not only prime agricultural land but is a center for machine manufacturing, paper making and food processing. The highest population density is found in Winnebago and Brown Counties, followed by Outagamie and Calumet Counties (Figure 70). In Brown County, as of 1970, 81.6% of the population lived in an urban area, and in Outagamie, 68.6%. By contrast, in 1970 only 28.1% of the population was urbanized in Oconto County and 43.4% in Marinette County.[1]

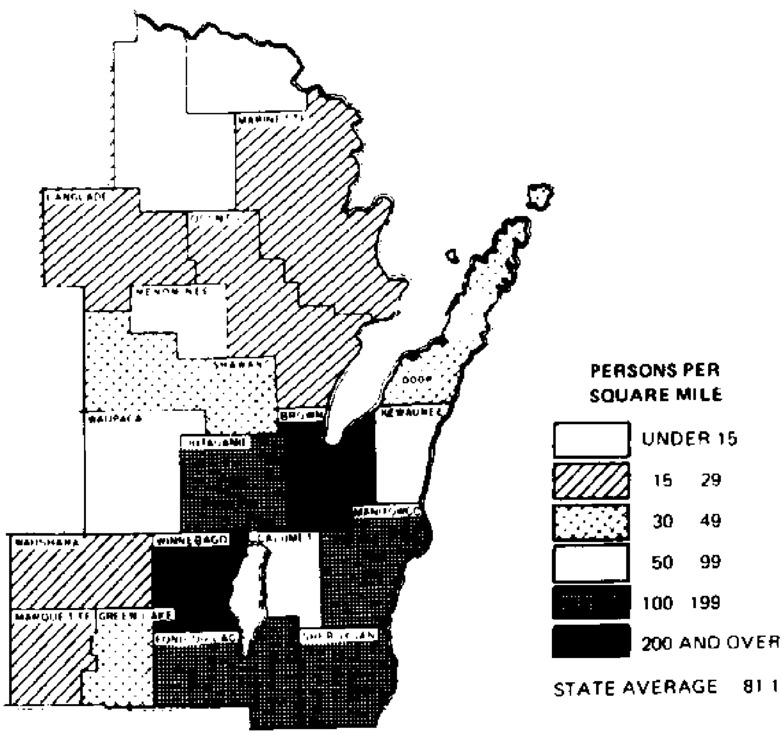

Figure 70. Population Density in Wisconsin.
From Wisconsin Statistical Abstracts, Wisconsin Department of Administration, Madison, May 1972.

Brown County includes the largest bayshore community, the city of Green Bay. As of 1972, the population of Brown County was approximately 170,000.[2] According to the revised 1975 estimates of the Brown County Regional Planning Commission, the county population will increase to about 210,000 by 1985 and to approximately 260,000 by the year 2000.[3] The city of Green Bay will make up a large share of that growth and is expected to reach 126,500 by 1985.[4]

Population growth in the Green Bay region has been primarily an urban growth since the 1930s. The population that had been drawn to the Fox Valley in the 1870s by the lumber boom and the subsequent industrailization of the region remained fairly stable until the Depression years. Then, as people left their farms and moved to the cities, population growth rates began to increase. During World War II and the post-war years, the manufacturing cities of the Green Bay region grew rapidly (Table 52). At the same time, growth in rural communities like Marinette began to slow down and then, gradually, to decline (Table 52). With the exception of those rural townships and villages such as Suamico, Bellevue, Hobart and Howard which became bedroom communities to the growing city of Green Bay,[5] most rural communities followed this trend up until 1970 (Figure 71). The population change in several Green Bay communities between 1960 and 1970 is illustrated in Table 53.

TABLE 52

Population Growth in Three Green Bay Region Cities Since 1900

	Appleton			Green Bay			Marinette		
Years of Census	Population	Change in Number	Percent Change	Population	Change in Number	Percent Change	Population	Change in Number	Percent Change
1970	57,143	8,732	18.0	87,809	24,921	39.6	12,696	-633	-4.7
1960	48,411	14,401	42.3	62,888	10,153	19.3	13,329	-849	-6.0
1950	34,010	5,574	19.6	52,735	6,500	14.1	14,178	- 5	---
1940	28,436	3,169	12.5	46,235	8,820	23.6	14,183	449	3.3
1930	25,267	5,706	29.2	37,415	6,398	20.6	13,734	124	0.9
1920	19,561	2,788	16.6	31,017	5,781	22.9	13,610	1,000	-6.8
1910	16,773	1,688	11.2	25,236	6,552	35.1	14,610	1,585	-9.8
1900	15,085	--	--	18,684	--	--	16,195	--	--

From 1970 Census of Population, Wisconsin, U.S. Dept. of Commerce (1971)

Table 53. Population Trends in Selected Green Bay Area Communities, 1960 - 1970

U.S. Census Data, 1970, U.S. Department of Commerce (1971)

Community	Population		% Change	Projections[2]	
	1960	1970		1985	2000
Green Bay	75,133	87,809	16.9	126,500	163,200
Howard[1]	3,485	4,911	40.9	9,800	15,000
*Ashwaubenon[1]	2,657	10,042	277.9	15,000	26,000
Bellevue[1]	1,007	1,736	72.4	6,200	20,100
Allouez[1]	9,557	13,753	30.5	17,900	22,800
*Suamico[1]	2,073	2,830	36.5	4,300	5,900
*Little Suamico[1]	989	1,138	15.1		
*Pensaukee[1]	869	863	-0.7		
DeFere[1]	10,045	13,309	32.5		
Oconto	4,805	4,667	-2.9		
Peshtigo	2,504	2,836	13.3		
Marinette	13,329	12,696	-4.7		
Sturgeon Bay	7,353	6,776	-7.8		
Egg Harbor	852	693	-18.7		
Menasha	14,647	14,905	1.8		
Neenah	18,057	22,892	26.8		
Brown County[3]	125,082	158,244	26.5	229,000	320,000

*Townships
[1]Near the City of Green Bay
[2]Brown County Planning Commission, based on 1960 census data.
[3]More recent census data suggest that the estimates for Brown County's population in 1985 and 2000 will be revised downward.

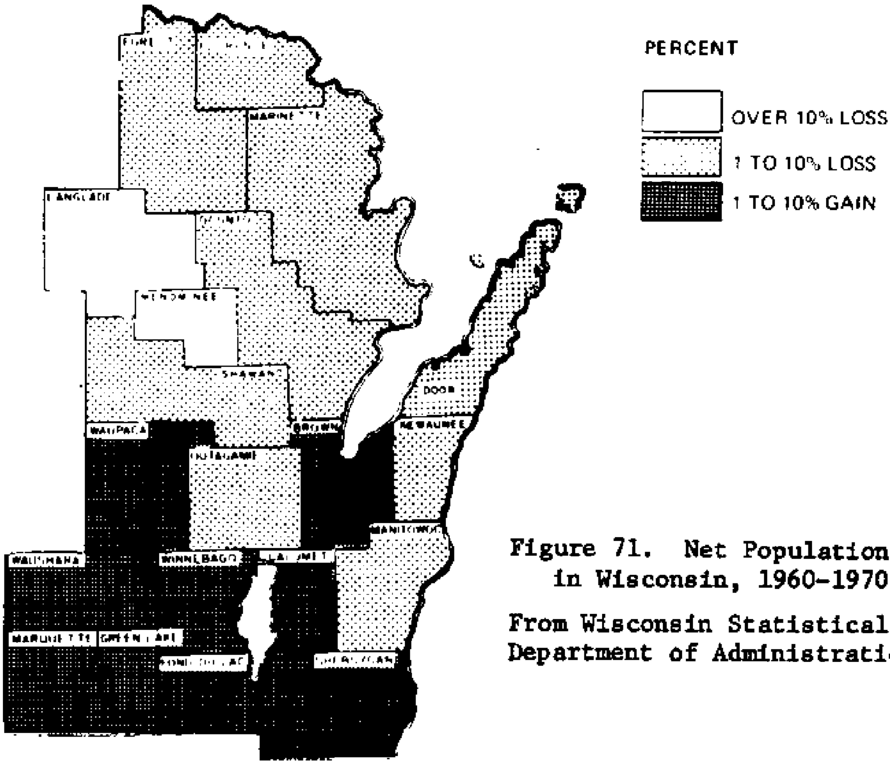

Figure 71. Net Population Migration in Wisconsin, 1960-1970.

From Wisconsin Statistical Abstract, Wisconsin Department of Administration, May, 1972

Gradual loss of population has also occurred on Michigan's Upper Peninsula. While Menominee County's population started a decline after the departure of the lumber interests in the late 1890s, Delta County's population continued to grow until the 1960s. However, between 1950 and 1960, there were employment losses on the Upper Peninsula, especially in agriculture, fisheries and mining.[6] The populations are now generally in slow decline.

Beginning in 1970, a significant change occurred in the population of northern Wisconsin. Over the five-year period from 1970 through 1974, all northern counties except one showed an increase in population.[7] Table 54. shows the changes for the counties of the Green Bay region. This rather surprising population shift has not been explained. However, it is suggested that among the contributing factors may be: (1) lower cost of living in rural areas; (2) appealing qualities of rural life; (3) increased job opportunities with increasing industrial location in rural areas; (4) high mobility allowing rural residents to work in urban areas; and (5) general improvement in rural services.[8] If these trends in rural population continue and accelerate, problems such as housing shortages and inadequate sewage treatment facilities could develop.

Table 54. Population Change in Selected Northern Wisconsin Counties, 1970 - 1974.

County	Population Change 1970-1974	Percent Change in Population Category		
		Communities 2,000	Communities 2,000	Rural and Unincorporated
Brown	+10,063	-1.8%	0	+1.8%
Door	+ 2,179	-1.3%	-0.2%	+1.5%
Florence	+ 277	-	-	0
Forest	+ 584	-	+0.2%	-0.2%
Marinette	+ 1,422	-3.3%	+0.1%	+3.2%
Oconto	+ 2,103	-1.1%	-0.1%	+1.1%
Outagamie	+ 4,427	-0.5%	+0.3%	+0.2%
Shawano	+ 1,888	-0.4%	+0.7%	-0.3%
Waupaca	+ 2,533	-0.7%	0	+0.7%

From "A Population Survey of the Wisconsin Upper Great Lakes Regional Commission Area by Counties and Selected Sub-county Jurisdictions," F. Alston, K, Exo, and J. Tarrant. Upper Great Lakes Regional Commission, July 1975.

Regardless of these latest population shifts, the age structure of the population in various Green Bay rural communities still generally reflects the fact that young people were leaving the area and births were declining until just recently. Conversely, the population structure in urban communities reflects the arrival of young people of child bearing age. The township of Howard, for example, essentially a recent suburb of Green Bay, had 46.2% of its population under 18 years of age in 1970. Only 3.7% of Howard's population was over 65 years of age.[9] On the other hand, in both Oconto and Peshtigo, approximately 18% of the population was over 65 and the percent of younger people was below average. These urban versus rural differences are also visible on the county scale (Figures 72 and 73).

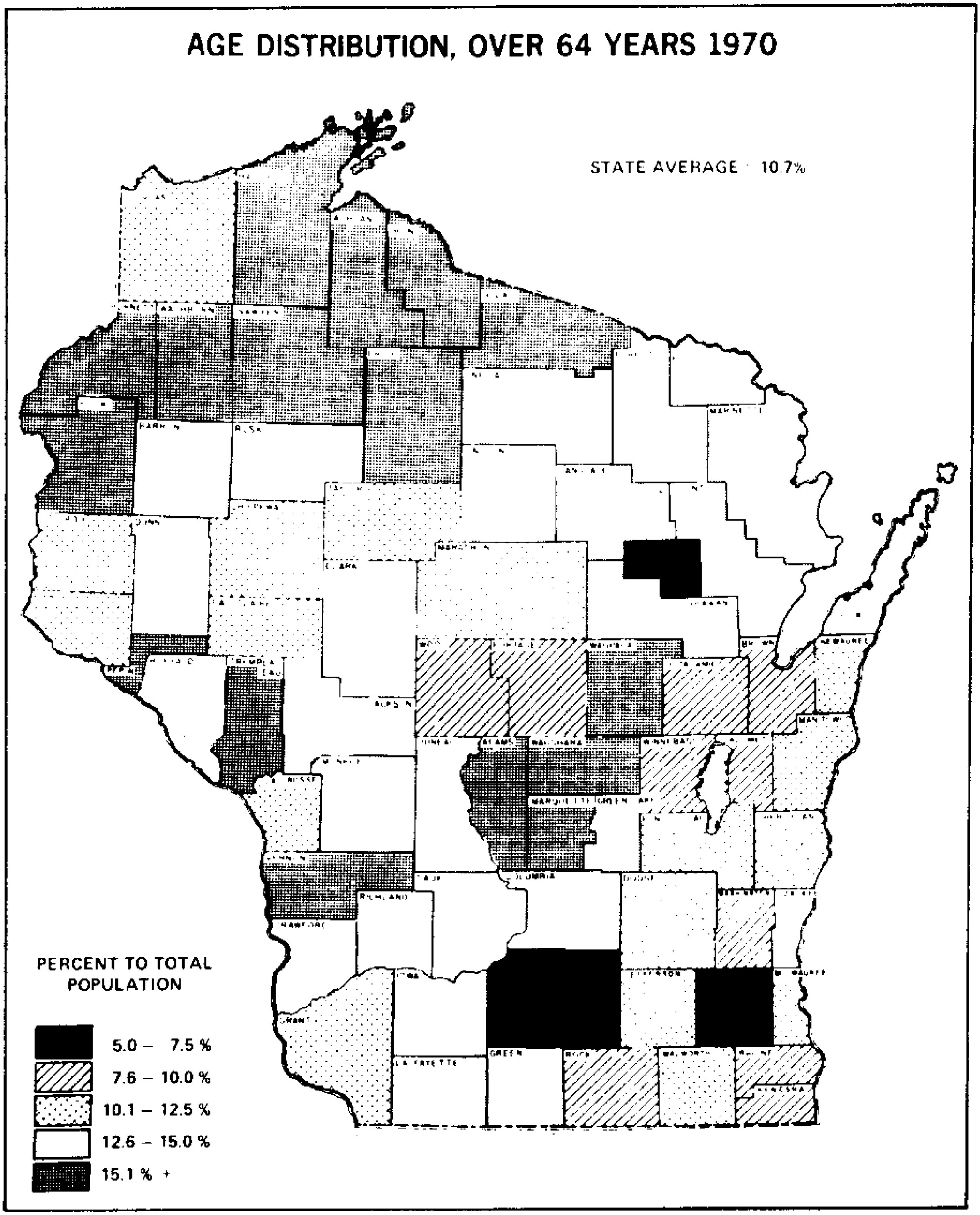

Figure 72. Age distribution, over 64 years 1970. From Statistical Abstracts, Wisconsin Department of Administration, May 1972.

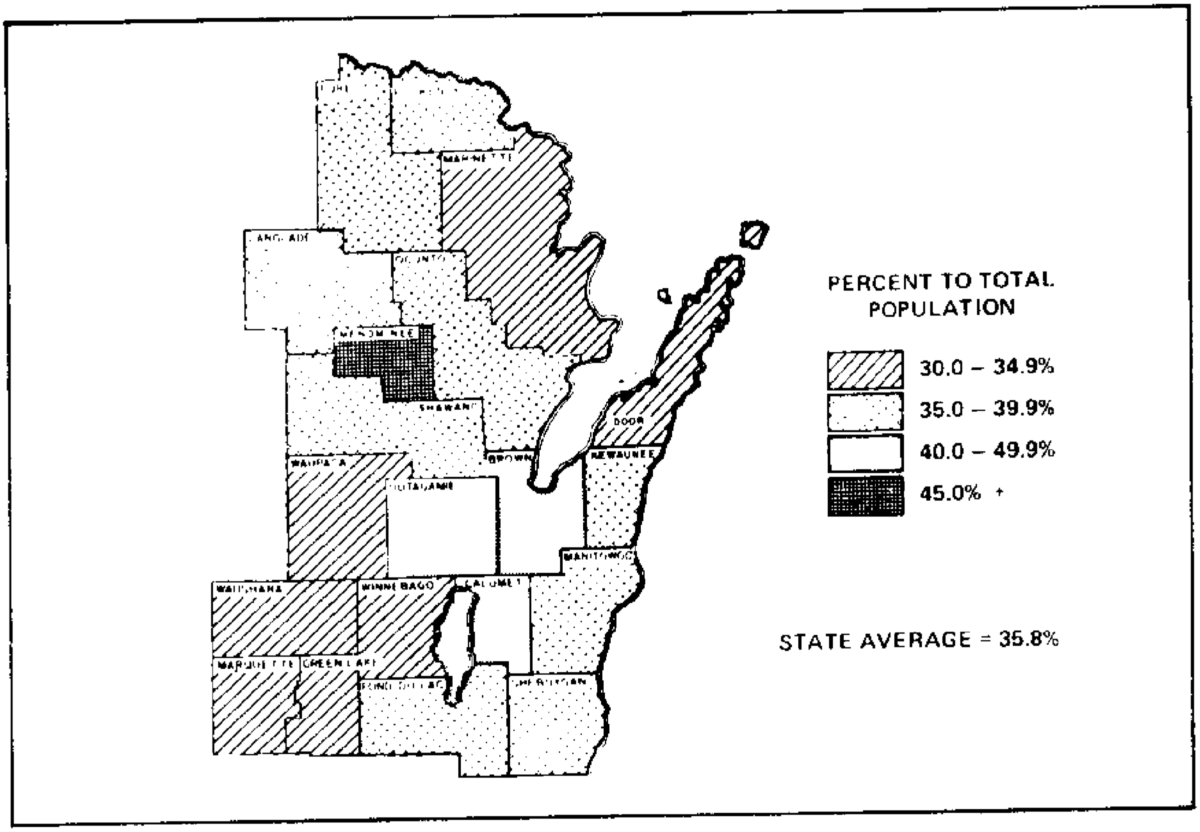

Figure 73. Age distribution, under 18 years 1970.
From Statistical Abstracts, Wis. Department of Administration, May 1972.

12.2 LAND USE PROBLEMS

As of 1974, Green Bay's mayor had a stated policy encouraging industrial[10] growth, and as a natural offshoot of that policy, encouraging population growth. However, other members of city government as well as the voting constituency were less certain of the desirability of an all-out growth policy. In the April 1975 mayoral election, the incumbent was defeated by a city alderman who had campaigned for managed growth with consideration to environmental concerns and the preservation of the central city.

The movement of people out of the central city and into the metropolitan fringe has been a matter of particular concern as Green Bay has been affected by a wave of urban sprawl.[11] Over the last 15 years, the city has added on by the annexation of parts or all of several adjacent communities, including the towns of Hobart and Preble. Green Bay has encountered great expense in bringing water supplies, sewage systems and other services of these annexed communities up to city standards.[12]

According to Green Bay planner Dale Preston, the city of Green Bay is trying to encourage those who want "country living" to settle in established satellite villages such as Wrightstown or Denmark (Figure 74). The planners would like to see areas such as these, with existing utility and sewage services, developed to their full capacity before new services are extended to outlying areas.

Brown County has a functioning comprehensive development plan and sponsors a program to assist small towns in designing their own development and zoning plans. However, the comprehensive plan in Brown County (as in many other counties) is not always followed and zoning laws tend to be enforced unevenly throughout the metropolitan area.[13]

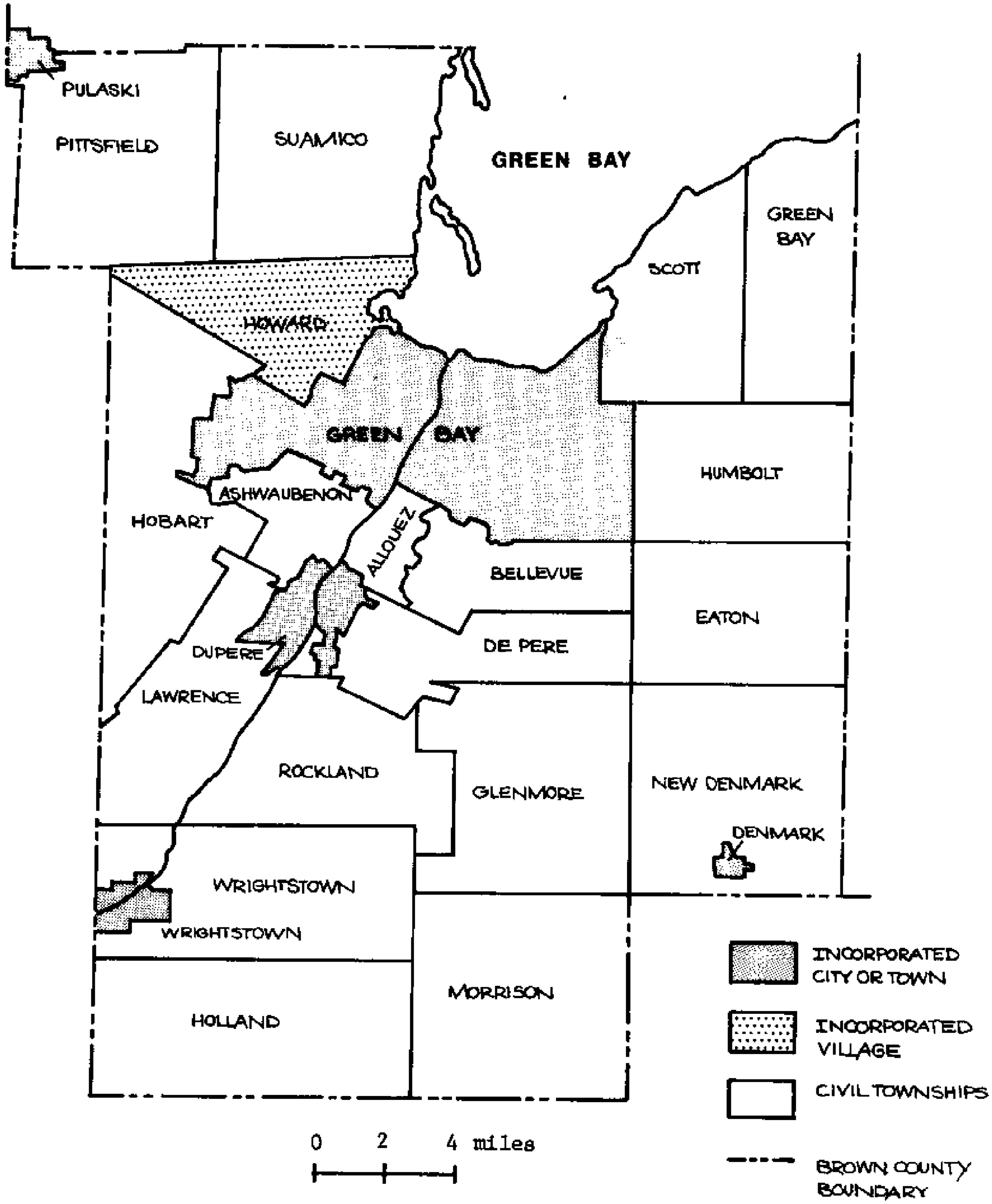

Figure 74. The Green Bay Metropolitan Area and Adjacent Municipalities From the U.S. Department of Commerce, Bureau of the Census

The spread of urban living out into the countryside has driven up agricultural land values in the Fox-Wolf River area. A 1973 study funded by the Wisconsin Department of Adminsitration showed that Brown County was an area experiencing "significant agriculture-urbanization conflicts as indicated by every statistic employed."[14] Figure 75 illustrates the degree of loss of agricultural land to urbanization. These conflicts over land use are expected to intensify in the coming decades with an increase of 10.2% in urbanized land in all counties of the watershed except Marinette. Marinette, along with Florence and Forest Counties, will experience only a 4.8% increase.[15]

Residential development has also moved northward from metropolitan Green Bay up the east and west shores of the bay. At the present time, 65% of the land between Green Bay and Marinette on the west coast is in its natural state, either as forest, agricultural undeveloped land, wildlife land, or recreational land. One percent of the land is industrial-commercial and 34% have been developed for residential purposes. From Green Bay to Sturgeon Bay on the east shore a different picture is evident. Only 34% of the land is in its natural state and 51% has been developed for residential use. Thirteen percent has been developed for recreational or urban open space use and 2% has been developed for industrial-commercial. North of Sturgeon Bay 39% of the land is in its natural state, with 31% of that being forest. Residential use occupies 33%, 4% goes to commercial use, and 24% to recreational and urban open space use.[16]

Much of the shoreline area north of the city of Green Bay was initially developed for second home sites. Second home ownership is not uncommon in the Fox-Wolf River region. As of 1970, census data showed that approximately one out of ten households surveyed in the city of Green Bay owned a second home. Approximately one out of thirteen households in Outagamie County had a second home.[17] The current problem, however, is primarily one of increasing numbers of people making permanent settlement along the coastal areas. This is especially true of the west shore where land has been relatively cheap—and of marginal quality—and where summer cottages are available to be converted to permanent homes.

Development of the shore northwest of Green Bay poses several problems. The land is primarily agricultural but is of only moderate fertility. Pasturing is the common use. It is low and sandy and the groundwater is close to the surface and easily exposed by development.[18] Where the sandy land is elevated, it suffers from excessive drainage. These factors pose serious problems for septic systems. Because of the environmental effects of sewage seepage and because of the costs of protecting these properties from shoreline flooding, both Brown and Oconto Counties have attempted to discourage development here. The main tactics are to limit sewer extensions and to strictly enforce state standards for septic systems.[19] But despite these efforts, one only has to glance at Green Bay classified ads for real estate to see that the Suamico area is still considered desirable property for "country living close to the city " (Figure 76). The fact that a number of ads mention "perc tests" indicate that the lack of sewer hook ups is no deterrent. According to county extension agents, people are willing to pay the considerable costs of special septic systems suited to wet sandy soils.[20]

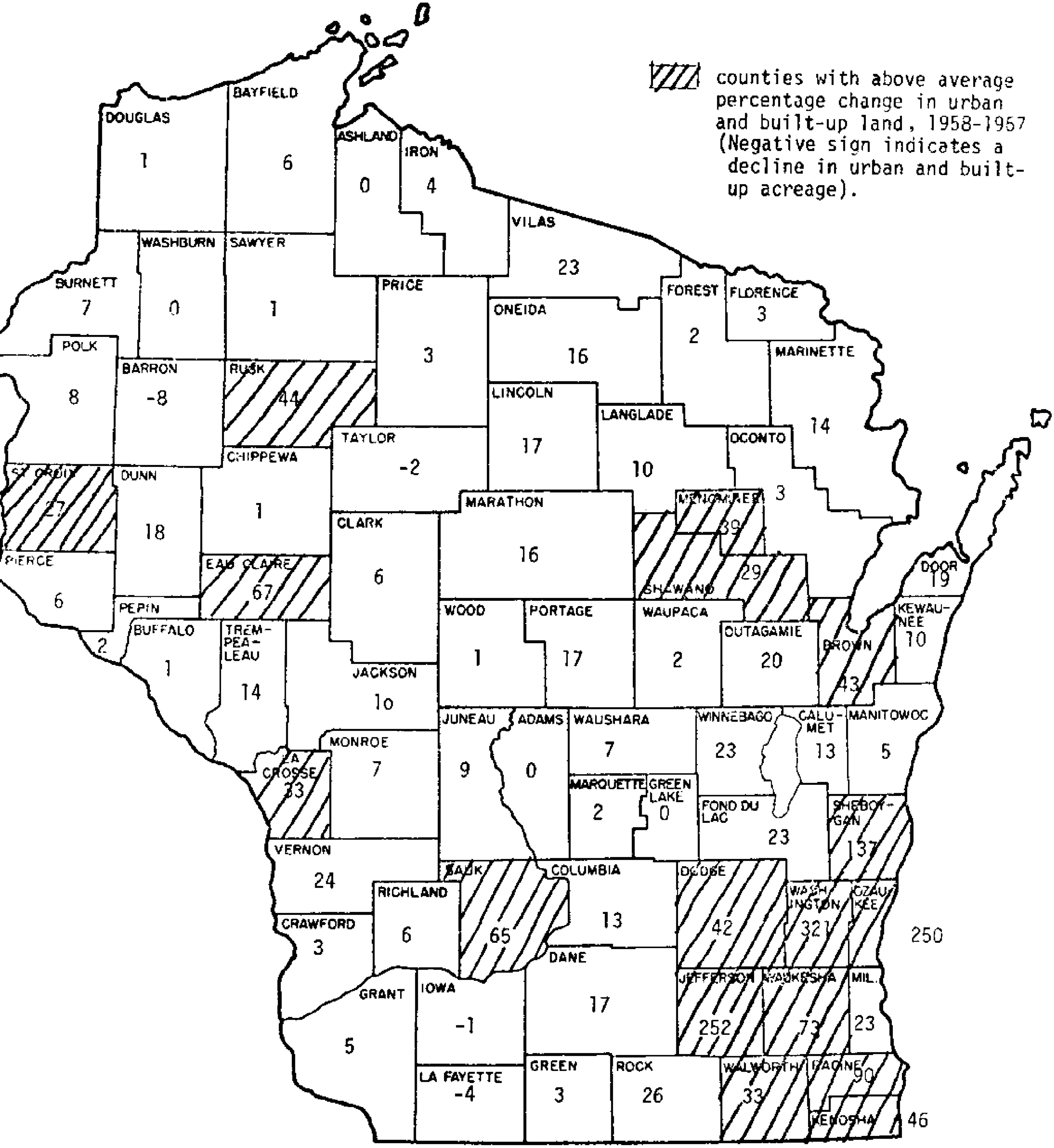

Figure 75. Percent Change in Urban and Built-up Land, 1958-1967. (State average 27.0%). Source: Soil Conservation Service, Wisconsin Soil and Water Conservation Needs Inventory, Madison. September 1970.

5 acre wooded parcels
among rolling hills and sandy soil.
Located in the Town of Little Suamico.
$7,500.

LaCount Realty, Green Bay
432-2956

40 acres. Half on high wooded land. Balance in pasture. Perc test taken and approved. 3 miles west of city limits.

10 acres west, near Sandlewood Golf Course, some woods. Also 10 wooded acres near Suamico, both perc approved. Low prices, 5 wooded acres, 10 minutes northeast.

Interstate Realty
468-1937

Choice wooded homesites, 1 1/2 to 10 acres. Near Flintville and Reforestation Camp.

White Pine Realty
494-9031

Large wooded lots of 1 1/2 acres or more in the exclusive Pine Wood Estates, Suamico. $5 -7,000. Restricted. Will build from your plans or ours. "Ken" Homes Construction and Real Estate.
499-0571

Figure 76. From Green Bay Press Gazette Classifieds, Wednesday, December 11, 1974.

Many prospective homebuyers are very conscious of the shoreline flooding that has occurred throughout the Lake Michigan area in recent years. In the Green Bay region flooding has been a problem on the lower east shore of the bay and for a considerable distance along the lower west shore. Local realtors claim that some flooded properties are currently impossible to sell. Well-built homes valued at $25,000 to $30,000 are not even being considered by buyers if some of the property is under water and there is little chance of salvage.[21] However, according to the same realtors, people are still interested in shoreline frontage if they feel that they will be protected from serious flooding or that the property can be reasonably reclaimed from the rising waters. Green Bay realtor Richard Vogels claims that after a dike was built along the lower east shore of Green Bay City, protecting it from high water, properties that had been previously unsalable were quickly bought up. He notes that people are so anxious for a piece of the shoreline that they don't object to having their new $60,000 house surrounded by old run down cottages. Leland Green, extension agent in Oconto County confirms the fact that there are still a number of people willing to purchase flood-prone properties and make the substantial investments necessary to live there. It appears that flooding and septic problems have slowed development on the shore, but that this slump will only last as long as the high water levels.

Table 55. Building Permits Granted in Door County, 1968-1973

	1968	1969	1970*	1971	1972	1973
One Family Dwellings	10	13	27	52	63	60
Two Family Dwellings	0	2	0	3	1	3
Multiple Family Dwellings	0	0	0	2	4	3
Churches	0	1	0	1	0	0
Community Buildings	5	3	4	2	4	5
Factory and Shop Buildings	0	3	2	2	3	0
Private Garage	23	16	19	22	17	16
Non-residential Alterations and Additions	9	9	13	18	24	15
Residential Alterations and Additions	32	63	63	46	53	54
Warehouses	0	3	0	2	5	0
Gasoline Stations	0	0	2	0	0	0
Schools	0	0	1	0	0	0
Municipal Buildings	0	0	0	0	0	3
Boarding Houses	0	0	0	0	0	1

*Bay Shipbuilding Company moved to Sturgeon Bay in 1970

From City of Sturgeon Bay Inspection Department records.

It is significant that the lower bay's poor water quality has not been the main factor in deterring development along the shore. Living on the shore with a view of the bay seems to be more important than actually being able to use the water for a diversity of recreation activities.

The demand for private shoreland property and the increased numbers of year-around residents can be expected to put increasing pressures on the wetlands, both in an economic sense and in an ecological sense. As more people seek recreation on the west shore, one can foresee that the wetlands will be eyed as potential recreation areas, needing only the appropriate landfill to make them pleasant beaches.

Perhaps some conversion of this land to beach or parkland will be necessary. However, the sacrifice of any of the remaining wetlands should be done only after very careful consideration. The taking of many small pieces of marsh can eventually total to a very large area.

Growth and sprawl has also become somewhat of a problem in the Sturgeon Bay area of Door County. The greatest change in land use has occurred since 1970 when the Bay Ship Building Company, a major construction operation, moved its facilities from Manitowoc to Sturgeon Bay.[22] Besides the ship yards, Sturgeon Bay has attracted a number of related small manufacturers and assembly plants. In the fifteen years prior to 1970, one piece of property was annexed to the city lands. Since 1970, eight different parcels of land adjacent to the city boundaries and totaling 250 acres have been annexed.[23] Apparently developers are not finding the kind of land they want in the city and most growth is expected to occur within a mile of present city boundaries. In anticipation of this, Sturgeon Bay is using its extra-territorial zoning rights to zone these border areas. The city assessor, John Taube, expects that Sturgeon Bay will have a population of 10,000-12,000 in 20 years. The arrival of Bay Ship Building brought a wave of both home and apartment construction to Sturgeon Bay (Table 55). Since many shipbuilders do not have the resources to buy or build their own homes, more apartments have been allowed to ease the housing situation.

In 1971 Sturgeon Bay revised its 1927 zoning ordinance. The old ordinance allowed that any zoned land could be used for a "higher," but not a "lower" purpose than its zoned classification allowed. The new ordinance, based on the state's comprehensive master plan for the area, is an "exclusive use" ordinance.[24]

Since Door County economy depends largely on tourism and agriculture, there has been concern in the county that land speculation will force out fruit-growing and other rural businesses that give the county much of its attractiveness. According to a draft publication of the Bay Lake Regional Planning Commission:

> A recent report from the Door County Planning Department (2-A8) indicates that there are currently 14 non-city subdivision developments with a proposed area of 752 acres for which 742 persons have already received approval or are awaiting final approval. In addition, applications are incomplete for 11 developments totaling 1,687 lots with a combined area of 4,162 acres and a population estimate of 10,000. Clearly this kind of rapid growth will create additional conflicts in the coastal zone and undoubtedly magnify existing ground water and surface water pollution problems if proper treatment facilities are not provided. Unfortunately only 4 of the 14 towns in the county have adopted the zoning ordinance proposed in the county's comprehensive plan.[25]

Door County as a whole, (and Sturgeon Bay) overwhelmingly supported Wisconsin's preferential taxation referendum, with farmers actively organizing support. The people of Door County, because of their insular situation and low population tend to consider themselves as one political and economic body rather than as a collection of individual municipalities.

Throughout the Green Bay region, the problems of urban sprawl and land use in general are aggravated by competition among municipalities for industrial tax base. Towns on the urban fringe of larger Green Bay cities are continually competing with the metropolitan area for the privilege of housing new industries. Generally, the smaller communities offer the enticement of fewer environmental regulations and less restrictive zoning laws. Frequently the leaders of these small communities are also major landholders. Thus, a town that is ill-equipped for rapid growth follows the self-interested course its leaders set—industrial, commercial, or residential expansion.

The city of Green Bay has been attempting to revitalize its older downtown commercial area and to bring new industry into the city. However, the city often finds itself competing with small neighboring townships that also wish to host new industries. Although Green Bay's competition with Preble declined after the town was consolidated with Green Bay, competition with the communities of Howard, Bellevue and Ashwaubenon continues.[26] A possible solution to this constant struggle for a larger tax base, might be a system of tax base sharing. A method used in Minneapolis-St. Paul requires that 60% of the taxes collected from industries on the urban fringe go to the county. This system discourages the promotion of industrial settlement simply as a means of creating a tax island. While the county does not directly control where industry settles, it does remove one undesirable incentive from the decisionmaking process.

But until this or some other solution is found, competition among cities for industrial tax base will continue to foster haphazard development and inefficient distribution of resources.

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PART III

Future of the Green Bay Ecosystem and the Role of Research

13. PROSPECTS FOR IMPROVED WATER QUALITY

13.1 BENEFITS OF CLEAN WATER

". . . producing or maintaining high quality water in many areas can be justified if justified at all, only on the basis of the recreational benefits it yields." Allen V. Kneese, Natural Resources Journal, October 1965.

The apparent truth of this statement was borne out by the Army Corps of Engineers' study on dredging and spoils disposal (see discussion on p. 99). It was also supported by the investigations of James Murray and Halvor J. Kolshus at UW-Green Bay. Their unpublished study was based on the assumption that many different water users in Brown County would benefit economically from clean water in the Fox River.[1]

The major industries of the Fox Valley (paper products and food processors) use large amounts of water. The paper companies, especially demand vast quantities of very clean water. It must be cleaner than drinking water and odorfree since paper absorbs odors. (Green Bay Packaging is the only paper company that can use relatively unclean water — this is for the manufacture of cardboard boxes.) Kolshus and Murray speculated that cleaner water would mean a substantial savings to industry.

They also hypothesized that clean water would be an economic benefit to the city of Green Bay. Green Bay now pipes most of its water overland from Lake Michigan, just north of Keewaunee. The rest is drawn from wells. The metropolitan area surrounding the city of Green Bay draws from 28 existing wells. Some of the area's large industries have their own wells. The quality of the groundwater varies by geographic location.

Commercial and sport fisheries, as well as recreation, were also expected to benefit from cleaner water. One of the greatest recreation needs expressed in the Brown County area is for swimmable water. By national standards of swimmable water area/person, Green Bay City has a deficit. And the commercial fishing industry, while perhaps the least competitive of Green Bay user groups, is the most exacting in water quality demands.

Kolshus and Murray found that their initial assumptions were only somewhat true. The paper companies consider that the cost of cleaning up intake water is only a small percentage of their total cost. Nicolet Paper Company figures only $50,000/year would be saved if the intake water were cleaner. (The way in which cleaner upstream water would really benefit the paper companies would be in the waste treatment area. The cleaner the Fox River water, the more effluent the mills could discharge and yet still remain within their abatement orders.) The investigators found that even if municipal and industrial waste were eliminated from the river, the paper mills would still have to remove suspended solids such as algae and agricultural sediments from the water before it could be used for the making of fine papers.

Kolshus and Murray calculated that the economic benefits of cleaner water to the city of Green Bay Water District would be minimal. Since Green Bay now has a fixed capital expenditure in its water pipeline from Lake Michigan, the line was expected to be used to its full lifetime which is another 50 years. The study did not stress the ultimate effect that greatly increased Green Bay pollution could have on the Lake Michigan water supply.

The investigators found that commercial fisheries and the recreation industry would benefit most clearly and most immediately from improved water quality. The gain to the fisheries, though easily visible, would be relatively small in terms of dollars. The gain to recreation would be most evident in property values. However, Murray felt the natural turbidity and roughness of the lower bay, and its fluctuating water levels, could be as much of a deterrent to recreation as poor water quality. Moreover, the parks and recreation department in Green Bay has built many of its new municipal swimming pools in conjunction with high school athletic departments to get maximum use of available swimming areas. Many of the new pools are indoors for year-around use. When offered the option of a well-maintained and controlled pool versus an open beach, most users will choose the pool. The municipal-school swimming pool system is another large capital expenditure to which the city has already committed itself.

Since land value seems to be the main beneficiary of improved water quality, Kolshus and Murray have sent a questionnaire out to property owners along the Brown County shore of Green Bay and along the Sturgeon Bay shore. The questionnaire asks for information on how land values have changed over the years. Murray hopes with use of public records to get a measure of the trend in values since about 1910.

13.2 ALTERNATIVE STRATEGIES FOR IMPROVED WATER QUALITY

In the course of this report, we have examined the historical and cultural development of the Green Bay drainage basin, reviewed past research on the bay ecosystem, and described some of the political and institutional arrangements presently in existence for managing or studying the bay ecosystem. Based on these observations we can make some reasonable predictions of what the future may hold for the environmental quality of Green Bay if certain pollution abatement policies are adopted. The predictions are condensed here into three alternative scenarios, although the real course of the future will certainly not be so simple.

Scenario I: Increased flow of pollutants into Green Bay and accelerated deterioration of the bay's water quality.

The bay's environment has deteriorated at a rapid rate over the last 35 years. This rate could be accelerated if the national economy suffered such severe setbacks that current anti-pollution measures were rescinded or postponed indefinitely in order to ease the financial burdens on industries and municipalities. It is unlikely that such a situation will come about, although industry already exerts considerable pressure on environmental protection authorities to ease up on water pollution abatement enforcement.

If the discharge of polluting wastes and nutrients to the bay were accelerated, the following changes could be expected in the bay:

(1) Increased levels of nutrients in the lower bay would stimulate increased algae production. This, in turn, would increase the amount of decomposing plant biomass in the lower bay and deeper parts of the middle bay. The decomposing material, plus other sources of BOD such as industrial and municipal effluents, would make heavy demands on the oxygen supply and increase the production of hydrogen-sulfide. This would cause more fish kills and the elimination of pollution-sensitive organisms.

(2) The anoxic zone in the lower third of the bay would persist longer in summer and cover a larger area of the bay the area of partial oxygen depletion throughout the year.

(3) That area in which only pollution-tolerant organisms now thrive would extend northward up the bay from its present locus in the lower third of the bay. Oligochaetes and midge larvae would comprise a larger proportion of the bay's total fauna. Clams, snails and mayfly larvae, which previously were important fish foods would disappear. Commercial fish stocks in the middle and upper bay would decline due to increasing eutrophication and decreasing oxygen levels.

(4) Communities such as Marinette which are located on the northern bayshore and take their water from upper Green Bay would have to increase water treatment practices or seek other water sources.

(5) Recreational use of Green Bay would decline as swimmers, boaters and fishermen sought more agreeable waters. Sport fishing would fall off in the lower bay as species like perch were driven out by anoxic conditions. Swimming in the lower bay would be completely discouraged and even the middle bay would lose what popularity it has as a swimming place.

(6) Bay-front property values would be seriously depressed in the lower bay area due to spring and summer scum algae blooms, fish kills, and obnoxious odors. Property values along the middle bay and Door County shores would also suffer some decline.

(7) More importantly, an increased rate of deterioration of water quality in Green Bay would ultimately lead to visible deterioration in the waters of Lake Michigan. The current on the west shore of Lake Michigan moves southerly and, as it passes the mouth of Green Bay, picks up water from the bay. This water is carried south along the lakeside shore of Door County. A polluted current of water southwest from Green Bay into Lake Michigan could damage recreational resources, fisheries, and property values along Lake Michigan's west shore. Most importantly, it would threaten to contaminate the Lake Michigan waters which supply the drinking water for the city of Green Bay and other Wisconsin communities.

This could be a serious problem in years ahead if large metropolitan areas increase their reliance on Lake Michigan for potable water. Indeed, this is very likely to occur. Water supplies for Brown County, for example, could become critical by 1985 if the townships around the city of Green Bay continue their rapid rate of growth.[2] Donahue and Associates engineering consultants have recommended that metropolitan Green Bay extend an additional 36 inch water pipe to Lake Michigan, use existing ground wells only as a reserve, and let the towns west of the city draw their water supply from an expanded well system.

Scenario II: Continuation of current pollution controls on point sources and moderate improvement, or at least no further deterioration, in water quality of the bay.

Current efforts to clean up water pollution in Green Bay primarily involve the curbing of gross municipal and industrial pollution and the reduction of BOD loadings from point sources such as sewage plants and paper mills in the Fox River Valley and along the other tributary streams. According to DNR data the enforcement of anti-pollution orders has been moderately successful in reducing oxygen demand in the lower Fox River. It is felt that this in turn should have positive effects on oxygen levels in the lower bay.

These positive effects, however, have been qualified by the continuing problem on non-point source pollutants, particularly nutrients. These pollutants, originating in agricultural run-off and storm sewer drainage have recently been shown by a Council on Environmental Quality report to have a major impact on the aquatic environment. Agricultural run-off contributes not only phosphorus and nitrogen fertilizers to the bay, but also add pesticides and herbicides. From storm sewers come street litter, plant debris, the nutrients released by decomposing organic matters as well as sulphur and heavy metals from vehicular exhaust. However, the initiation of a proposed Section 208 study in the Fox River Valley would direct special attention to the curtailment of non-point sources as part of an area-wide water quality management plant.[3] (Section 208 of the 1972 Amendments to the Federal Water Pollution Control Act requires wastewater management planning by a metropolitan area in order to provide overall co-ordination of the many provisions of the act as they apply to that area.[4]) The proposed study for the Fox Valley would also look at alternative strategies for meeting the improved sewage treatment requirements of the Water Pollution Control Act.

Assuming that (1) point source abatement reduces municipal and industrial BOD loads to the bay and (2) the nutrient and BOD loads of storm water and agricultural run-off continue to flow unabated to the bay, the following results could be expected in the Green Bay ecosystem:

(1) Slightly decreased levels of nutrients in the bay could cause slight reduction of algae blooms in the bay. There would also be a corresponding reduction in oxygen demand from decomposing plant material. However, nutrient-rich bottom muds could be expected to continue releasing nutrients to the water column for an unknown period of time. This nutrient supply, combined with slightly reduced turbidity and slightly increased light penetration into the water column could possibly produce an actual increase in algae production.

(2) Reduced influx of oxygen-demanding effluents from the watershed would enable the bay to maintain somewhat higher oxygen levels year around and would reduce the size of the anoxic zone in the lower bay. In addition, there would be less production of hydrogen sulfide, and the attendant offensive odors, and fewer fish kills due to oxygen depletion.

(3) Pollution tolerant animals would not continue their spread up the bay but would begin a gradual back toward the mouth of the Fox River. Fish, other than strictly pollution-tolerant species, would be more abundant in lower Green Bay. Yellow perch and white bass especially would be expected to increase in numbers. Commercial fish stocks in the middle bay would also increase somewhat.

(4) Green Bay's use as a recreation area would probably NOT increase greatly. Due to the continuing influx of nutrients from non-point sources, lower Green Bay will continue to be eutrophic. And because the bay is a shallow wind-driven system, it will remain relatively turbid. Even though the water was technically clean — free of sewage contaminants and toxic materials — the lower bay would not be a particularly pleasurable place for swimming.

However, the water's technical cleanness may be an important psychological factor in promoting greater use of the bay for boating, or as a desirable open space to be included in the design of bayshore parks, golf courses or other facilities. When the Green Bay Metropolitan Sewerage District completes its new treatment plant near the mouth of the Fox, and when the city of DePere completes its sewage plant, many Green Bay residents anticipate using Bay Beach Park.[5] This park at the rivers mouth has been closed for almost 35 years because of contaminated water. Thus, the technical cleanliness of the beach and the possibility of a small boat marina in the vicinity in the future[6] hopefully would foster some increased recreation in the lower bay.

(5) In the lower bay, the value of bayshore property for recreational use would probably not increase much.

This second scenario appears to be the present management goal of the Wisconsin Department of Natural Resources, that is, to have technically clean water, and take steps to prevent the further degradation of the middle and upper bay. The emphasis is on preventing the development of major health hazards in the lower bay and limiting the spread of polluted water into Lake Michigan. The approach is to control the release of sewage and toxic materials such as heavy metals and pulp wastes from point sources into the bay system.

<u>Scenario III</u>. The systematic elimination of both point and non-point sources of pollution and a major improvement in Green Bay water quality.

This scenario presents the ideal, but perhaps unrealistic, water clean-up policy. Its success depends on (1) a massive investment in facilities for the treatment of urban stormwater run-off and (2) a program, as yet undevised, for controlling the flow of eroded soil, nutrients and pesticides from the agricultural areas of the watershed. Such a program might require the licensing of operators to apply agricultural chemicals or employ some other device that will minimize excessive use of these materials. Whatever method would be chosen, the control of non-point sources of nutrients and toxins would result in a significant improvement in water quality. The process of recovery would be the same as that described in Scenario II, only magnified. There would be a lag period of unknown duration in which nutrients in the bay sediments would continue to be released to the water column. During this period there might be little visible improvement in the bay.

As in Scenario II, these pollution abatement measures would not be able to totally eliminate the eutrophic and turbid conditions of the lower bay. However, the production of valuable fish stocks could be expected to increase in the middle and lower bay, the recreational value of the lower bay (particularly for fishing and boating) would certainly increase and the bayshore property values would also rise. Which of these strategies is the course of the future and what its actual success will be, depend largely on socio-economic conditions in the Green Bay watershed. These conditions include population growth, land use trends, the general state of the economy and the demand for Green Bay's resources and products. While these factors are partly determined at the local level, they are strongly influenced and swayed by regional and national trends. Dwindling petroleum supplies, for example, could force shippers to take a new look at boats and barges as an energy efficient transport mode for goods and people in the Green Bay-Fox Valley system. (As discussed on p.251 water transport of goods between Green Bay area communities is now almost non-existent, the boats having been replaced by the truck and the auto many years ago.) In its ties to energy and resources, the future of Green Bay cannot be separated from the future of the entire United States.

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14. RESEARCH NEEDS

14.1 EVALUATION OF PAST RESEARCH

In 1969 the Wisconsin Sea Grant College Program initiated research work on the Green Bay ecosystem. This project was designed to include all aspects of the ecosystem: biological, physical, chemical and geological. The institutional, economic and sociological aspects of water resource use and water quality management were also to be considered. This program was continued for four years at funding levels indicated in Table 56 . In 1973 the Sea Grant director terminated the project in order to evaluate the research that had been done to date and to decide on future directions. This review is part of that research evaluation.

TABLE 56

GREEN BAY RESEARCH PROJECT FUNDING
(1970-1974)

Year	Funds
1970-71	$157,500
1971-72	196,800
1972-73	134,200
1973-74	90,607

The data gathered over the four-year period have provided part of the necessary base for understanding the Green Bay ecosystem and managing the forces which effect it. The successes of the research program are many and have been discussed in this report. In general, the research has provided good information that offers starting points for future work. However, because the initial aim of the project was to sample a broad scale of bay problems, the research parts often have little direct relationship to each other. Also because of this sweeping approach and the method of project management, the research itself is of mixed quality and utility. These problems were at least partly recognized from the onset of the project. But because of the potential value of the research and the magnitude of Green Bay's problems, it was decided to push on with the chosen approach.

With the benefit of hindsight, we conclude that the early decision to press ahead was probably correct. Much needed information was obtained and Sea Grant program funds were distributed to sectors of the university system where they were needed for the continued development of environmental research capabilities. The decision to pause and evaluate the completed project work was also probably correct since the project had grown quickly and the need for a cohesively designed research focus had become evident.

14.2 SUGGESTED TOPICS FOR FUTURE RESEARCH

As we have seen, the Green Bay problems are myriad and their solutions difficult. But the Green Bay region is presently at a turning point for future development, and the activities of the Sea Grant program can be of direct benefit in shaping the future. In particular, Sea Grant's research program can aid in the coastal zone management activities now being initiated by the state of Wisconsin and the Bay Lake Regional Planning Commission.

Many coastal problems are directly related to the interactions of land and water in the littoral zone. A better understanding of the littoral environment and its role in Green Bay is essential to future studies on Green Bay's wetlands, commercial fisheries, fluctuating water levels, sedimentation rates, chemical cycling and recreation potential. Consequently, a number of the recommended study areas focus in whole or part on the littoral zone.

The following suggested research priorities set out major information needs for the Bay which will be useful for bay management. The common thread in the suggested research is that it all has direct relevance to solving the problems that are now or soon will be confronting the bay.

(i) Assessment of the impacts of fluctuating water levels

A prime research need of the Green Bay ecosystem is an understanding of the effects of fluctuating water levels over the past decade. There has been a major turnabout from the extreme low water of 1964-66 to the prevailing high waters of today. These changes in water levels have had major effects on the bay ecosystem, as described in the dicussion of the littoral zone. Four subtopics of major concern that could be addressed by research on fluctuating water levels are listed here:

(a) Identification and evaluation of areas to be flooded or drained at various water levels and under various weather conditions.

Information is needed on which parts of the bay shore would be flooded or drained at various water levels and with compounding factors such as seiches, winds, and storms. Base maps of the existing conditions can be constructed using high altitude overflight and combining these with historic records of flooding, or dredge-and-fill applications for the bay. Identification of these areas would be of particular use to counties working on shoreline zoning programs. Under the floodplain management concept this effort would identify and zone those areas likely to be flooded and/or that would need protection from high water. It would also identify those areas which would be most in need of dredging to provide water access during periods of low water. While this information would be of obvious value to those interested in shoreline development, it would also be of great public benefit by providing resource managers with detailed data with which to plan future shoreline use.

(b) Evaluation of the effects of prolonged flooding on the littoral zone of western Green Bay

Ecologists often have said that the littoral zone is the most important part of an aquatic ecosystem (Ketchum 1973). The littoral zone is highly productive and acts as a buffer against physical changes in the ecosystem. It is also in this zone that nutrients are trapped and used, that nursery grounds and spawning grounds are found, that wildlife habitat is provided.

In Green Bay, high water levels have thrown the littoral zone into a period of rapid and marked transition. Much of the littoral zone has been lost under the rising water levels. The effects of this loss on the Green Bay ecosystem are presently unknown and difficult to assess because there is little or no base line data. However, we now have the opportunity to observe to what degree the zone is able to shift and re-establish itself, how long such a change will take, what processes are involved in recolonization of the littoral, and what effects the loss of this zone has on fisheries production and migratory waterfowl.

(c) Evaluation of the possible dilution of pollutants by high water levels and increased water volume

It has been claimed that the current high water has neither diluted pollutants nor reduced eutrophication in the lower bay. While this proposition seems to have little actual support from the research done to date, there is also little support for the contrary position--that is, that high waters of the past two years have caused a resurgence of sport fishing activity in the bay and have also ameliorated the previously critical low oxygen levels in the lower bay.

An immediate need is to construct a hypsometric curve for the bay. This will relate change of water level to change in volume and give some insight as to real diluting capacity of current water levels.

Through continued monitoring we have the opportunity to examine the effects of current and future high waters on pollutant levels in the bay.

(d) Evaluation of water levels effects upon mass water movement within the lower bay

The lower bay is a shallow, wind-driven system. As such, changes in water level of two, three and four feet in the bay have major effects on the circulatory patterns. Research on this topic could be tied in with the verification of existing physical models which describe and predict the characteristics of mass water movement within the bay. These models are as yet unconfirmed by real life observation.

(ii) Inventory of Green Bay Wetlands

Ninety-five percent of all of Wisconsin's Great Lakes' wetlands are located on the west shore of Green Bay. Wisconsin's wetlands in general have been reduced from 5 million to 2.3 million acres in the last 50 years. It is generally believed that these wetlands are critical environmental areas and, as major concentration areas for wildlife, deserve full protection. To date, we have primarily topographic maps and ownership maps of wetlands areas. However, there is little in the way of habitat inventory or assessment of marshland quality. Identification and analysis of Green Bay wetlands could be of benefit in coastal zone management by directing attention to those areas which are critical from an environmental standpoint. Identification should include the location, size, ownership and qualitative value of the wetlands.

(iii) Evaluation of agricultural and urban run-off as nutrient sources to Green Bay

It is suspected that the nutrient loads in agricultural and urban runoff from the Green Bay watershed are substantial and could be major stumbling blocks to efforts to cleanup the bay. It is presently unknown exactly what proportions of nutrients entering the bay come from farm and municipal runoff. However, agricultural lands are thought to be a major source of both pesticides and nutrients. What amount of this material enters the bay directly and what proportion enters indirectly via effluent-stimulated algae growth in Lake Winnebago is also unknown. However, researchers in the area generally agree that non-point source pollution is a major problems and will remain so until sometime in the future. Analysis of the amount of agricultural and urban runoff reaching the bay and its effect in the lower bay could be a prime contribution to future bay management. However, this is a difficult task and extends Sea Grant research beyond the coastal area and into the watersheds. For this reason such research might be more appropriately done by the state, by the Environmental Protection Agency, or through the University of Wisconsin Water Resources Center, which has research under way on this issue in other regions of Wisconsin.

(iv) Assessment of Green Bay fish stocks, fish species interaction, and the location and condition of critical fish habitats

It is surprising how little we know of commercial and sport fishing within the bay. Research of prime importance for the management and understanding of the fisheries are:

1) The size of the fishing stocks as they presently exist within the bay.

2) The location of the spawning and feeding areas of various fish species and the extent to which these areas diminish or increase during periods of high and low water.

3) Effects of changing water levels on species competition, specifically competition between alewife and perch.

4) The impact of carp on the bay ecosystem: damage to wetland vegetation and the productivity of other fish species; feasibility and impacts of commercial carp harvest.

5) Description of the discrete stocks of chub, herring and whitefish: the movements, growth patterns, and population size and profile of the various stocks of each species.

6) An estimate of Green Bay's alewife population: size, areas of concentration, movements, their importance as prey in Green Bay (the upper Bay vs. the lower Bay).

7) Differences--or similarities--in the food webs of lower and upper Green Bay biotic communities and how the current food webs effect specific fish stocks. The food web of salmonids and alewives has drastically changed the food links within the bay.

These topics could easily fit within the auspices of existing research efforts being conducted by Sea Grant on fisheries.

(v) Verification of the physical parameters of Green Bay as predicted by models

Currently there are five models available which look at different aspects of Green Bay's chemical and physical systems. The focus of these models ranges from specific areas within the lower bay to the whole lower third of the bay. To date none of the models have been verified and several of the physical models predict patterns of currents as yet unobserved within the bay.

The empirical evidence on water movements, on the other hand, has primarily focused on surface conditions and following the Fox River plume as it moves north. There must be some meeting between the empirical evidence and the models. Verification of models is extremely expensive, requiring both ship time and the cooperation of government units and universities. Perhaps the role of Sea Grant in the area of model verification should be to work with EPA and DNR as a consultant and a participant but not as the prime funding source. Sea Grant, however, does have a legitimate role in helping to maintain the quality of research being conducted. Yet, Sea Grant is not currently represented on the DNR advisory committee that is working on development of the Green Bay model.

Future studies of Green Bay's currents should be done with an eye to the direct use of the data in selecting power plant sites. Presently the major source of thermal effluent in the bay is the Wisconsin Power and Light fossil fuel plant at the mouth of the Fox River. However, potential power plant sites are located on the bay's west shore and with the growing populations of metropolitan Green Bay, these sites could be pressed into service in the future. Our knowledge of the bay's currents indicates that any thermal effluent on the west shore of the Bay will be conducted southward toward the critically polluted area presently with Long Tail Point. Though the development of future west shore power plants is not imminent, good physical data will be critical when the decisions are made.

(vi) Identification of sources and rates of sediment deposition in Green Bay

Sedimentary material is accumulating at an extremely rapid rate in the lower third of the bay. Identification of this material has not been made, but it appears to be largely a combination of silt and organics, washed in from the lower Fox Valley. However, the Sea Grant survey work has not provided information on the sources and the current rates of deposition in the bay. Knowledge of these two parameters would be of some use in predicting the future of the bay and the effects of this deposition rate on shipping development within the bay.

(vii) Analysis of the present distribution and sources of microcontaminants in Green Bay and their effects on the bay's biota

Microcontaminants in Green Bay have received little attention. The chlorinated pesticides and polychlorinated biphenyls are two groups of compounds recognized as serious pollutants, yet their present distribution in the bay is largely unknown. In addition, other contaminants, yet unrecognized, are undoubtedly being contributed by the heavy industry and agriculture of the watershed. It is important for future management of the bay that we known what kinds of contaminants have already accumulated in the bay and what kinds are continuing to enter the bay. Specific research topics are:

1) The current status of aldrin, dieldrin, DDT and PCBs in the bay water, sediments and biota.

2) The current sources of these microcontaminants in Green Bay's tributary streams.

3) The affect of these contaminants on the food webs and reproduction of aquatic organisms in the lower bay.

4) An inventory of all contaminants presently entering the bay which are potentially important to the system because of toxicity through biological concentration.

This report has criticized past work on microcontaminants for poor or inadequate sampling techniques or analysis. Although microcontaminant sampling is difficult by its very nature, it must be done if we are to avoid the kind of contamination of our aquatic resources that has already resulted from carelessness and ignorance in the use of PCBs, mercury and pesticides.

(viii) Evaluation of recreation needs and potentials

Coastal zone management is becoming a reality in the Green Bay region and Sea Grant has an obligation as well as an opportunity to tie in and assist in this effort. Past Sea Grant research has assessed various uses of Green Bay's coastal zone, particularly its uses as a recreation area. Ditton (1974) recently pointed out that the current economic situation will force people to seek recreation closer to home. This could mean an increase in recreation use of Green Bay. If ferry access between the Door County Peninsula and the west shore of the bay should ever come into existence, or if a Michigan-Wisconsin park is developed on the islands of northern Green Bay, there is little doubt that the northwest shore of Green Bay would be subjected to greater recreation pressures than at present. Currently, Wisconsin and Michigan are attempting to determine whether the area should be developed by the federal government as a national park, or whether the states should proceed in developing the islands as a low density interstate wilderness park. A decision is hoped for by the end of 1975.

Any information developed by Sea Grant which would aid in the management of this park and adjacent coastal zone areas would be of benefit.

The UW-Extension Recreation Resources Center and the DNR are already looking at the recreation resources and the future recreation supply and demand situation of Wisconsin's coastal counties. Sea Grant efforts should attempt to tie in with this part of the Coastal Zone program. Expertise in both wetlands and recreation disciplines could be brought together by Sea Grant to determine what kinds of development are suitable to Green Bay's western shore, and how the environmental impacts of recreation can be minimized in this area.

Although preliminary work has been done on boating, boating needs and the economic impact of boating in the Green Bay area, further study is needed on specific facilities necessary to increase boating participation in Green Bay's waters.

At least one municipality on Green Bay's shores has expressed the desire for more information on the management of urban offshore areas. Specifically, methods are needed for regulating the recreation use of near offshore waters. Methods might include the zoning of waters for active or passive recreation that is compatible with adjacent shoreland usage. Methods for regulating recreation on nearshore ice in winter are also needed.

Finally, information on design techniques for the urban shore would be welcome to those Green Bay communities which are attempting to maximize shoreland use while retaining or enhancing the shores aesthetic qualities. Research in this area might focus, for example, on the use of vistas of water bodies as a means of "expanding" the limited open space in a confined urban setting.

(ix) Analysis of the future of shipping in Green Bay

As we have seen, the city of Green Bay has proceeded with the development of Bay Port, a bayshore site designed to house general industry and a possible future port facility. Bay Port was partly promoted in hopes of generating more jobs in Green Bay and increasing the port of Green Bay's participation in interlake shipping. Since the completion of Eric Schenker's studies on Green Bay shipping (funded by Sea Grant), there have been important economic changes as well as physical changes in the size of ships and the type of shipping being conducted in the bay. Schenker's earlier analysis could be usefully updated to describe these recent trends and their implications.

A related area of study concerns the effects of regular harbor maintenance and its accompanying dredge and fill activities. Spoil disposal, especially of the polluted materials from bays and harbors may cause environmental problems. The environmental solutions to these problems must be examined in light of future recreation, commercial fishing and shipping industry needs.

14.3 MANAGEMENT OF FUTURE RESEARCH

It is generally felt that a Sea Grant research program is again warranted for study of the Green Bay system. While the methodology to be used in initiating and controlling the program is undetermined, one thing is clear: there must be more active management in order to provide quality control and to integrate projects into the overall research plan. It is suggested that quality control can best be achieved through the appointment of a full-time project manager who is directly responsible for overseeing the projects, assuring that their funding goes smoothly, reviewing research progress, and keeping the Sea Grant administration informed on the program's direction.

Besides the multi-faceted program already described, there is another potential approach. This is to put together a task force or team of specialists for a limited period of time and with a reasonable level of funding to give concentrated attention to a particular assigned problem.

Regardless of the manner of delegating the research projects, the program must have conceptual integrity, an agreed upon context in which all the individual projects function. It should be the task of the program manager not only to manage the mechanics of the program, but to provide the overviews and broader concepts. He should be aware of the effects that various alternative policies, decisions and natural events could have on Green Bay and its use as a resource. Accordingly, a recognition of alternative future trends and their impacts should be a "built-in" part of the research program. It should be an important factor in assessing probable implications and applications of research results and in moving "drifting projects" back into the main stream. A firm grasp on the broader picture of drainage basin problems—physical, biological and cultural—should put all future Green Bay research into clearer perspective.

Along this line, it is strongly recommended that the Green Bay research team develop stronger ties with Michigan scientists and planners who are concerned with the bay. In preparing this review, it was surprising to find that many Wisconsin scientists and many local officials in the Green Bay region often had no knowledge—or interest—in who their counterparts were on the Upper Peninsula and what they were doing. It is recognized that Wisconsin research should focus primarily on problems within the state's boundaries. Yet it seems unrealistic for Wisconsin scientists to hope to study Green Bay as a total ecosystem and come up with useful recommendations for its management without seeking some cooperation from Michigan, the sole proprietor of the northern bay. In this regard, researchers should build upon the interstate contacts that have been established among regional planning offices.

It is suggested that when and if the Green Bay project is re-instituted, and after it is firmly on its feet, efforts be made to establish at least an informal bi-state committee on Green Bay problems and research needs. Michigan as well as Wisconsin could certainly benefit from the contact. What is presently a Wisconsin water quality problem will eventually move northward and become a Michigan problem unless the deterioration of lower Green Bay is curbed soon.

APPENDIX
SAMPLING STATION LOCATIONS

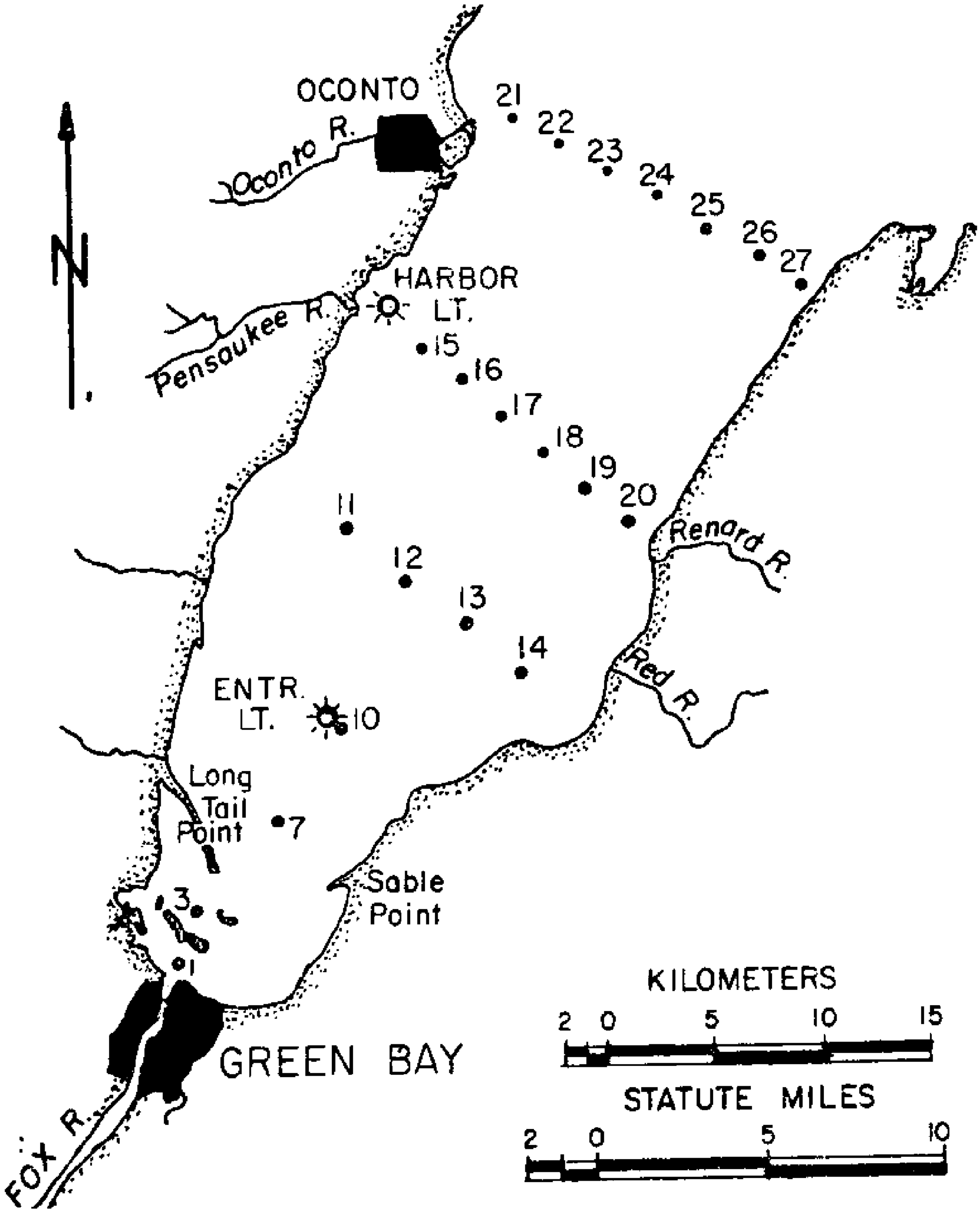

Figure 77. Sampling Stations for Light Penetration.
From Bates in Howmiller and Beeton, eds, 1971.

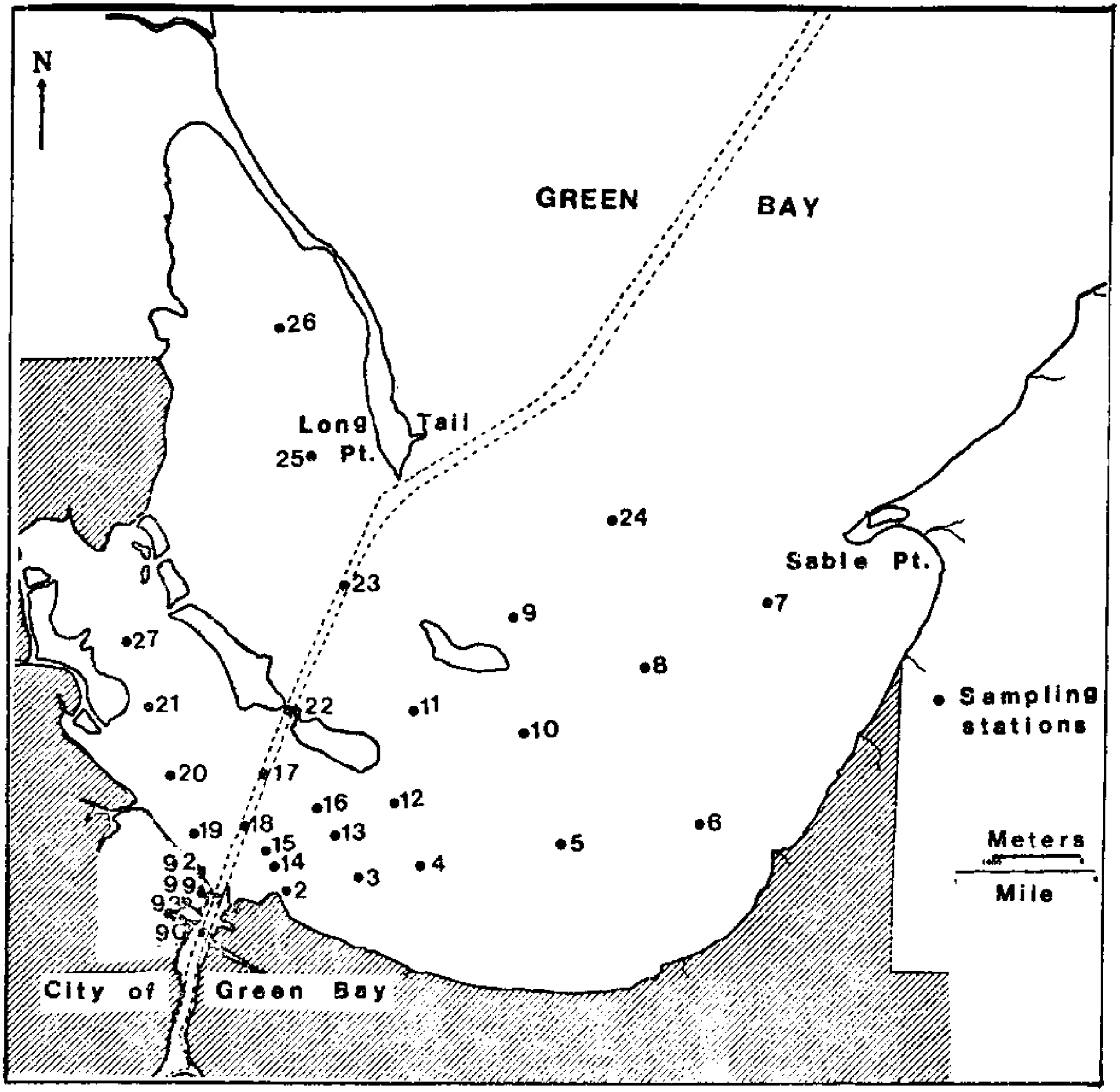

Figure 78. Water Chemistry Sampling Stations of the Wisconsin Public Service Corporation, 1974. Lower Green Bay Stations 1-27; Pulliam Plant Stations 90 (river composite); 92,93(inlets); 99 outfall.

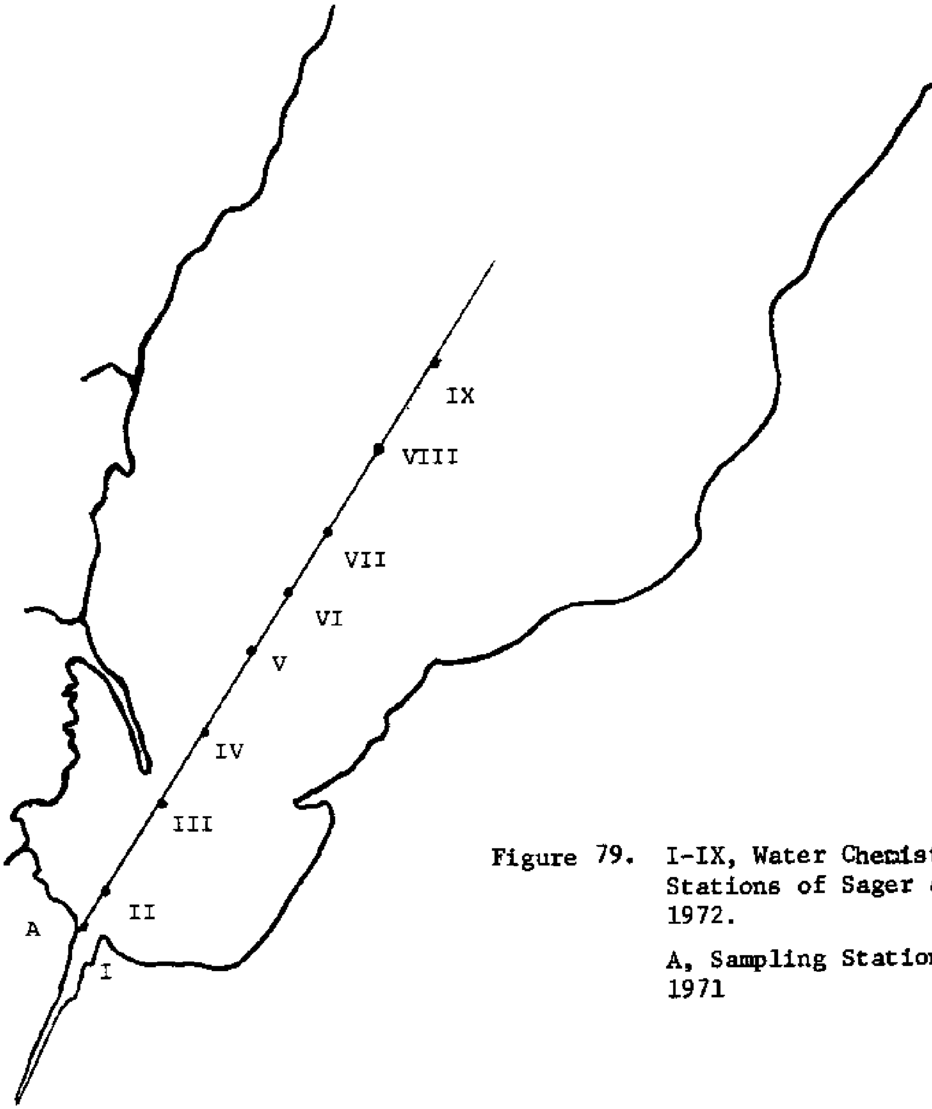

Figure 79. I-IX, Water Chemistry Sampling Stations of Sager and Wiersma, 1972.

A, Sampling Station#10 of Sager, 1971

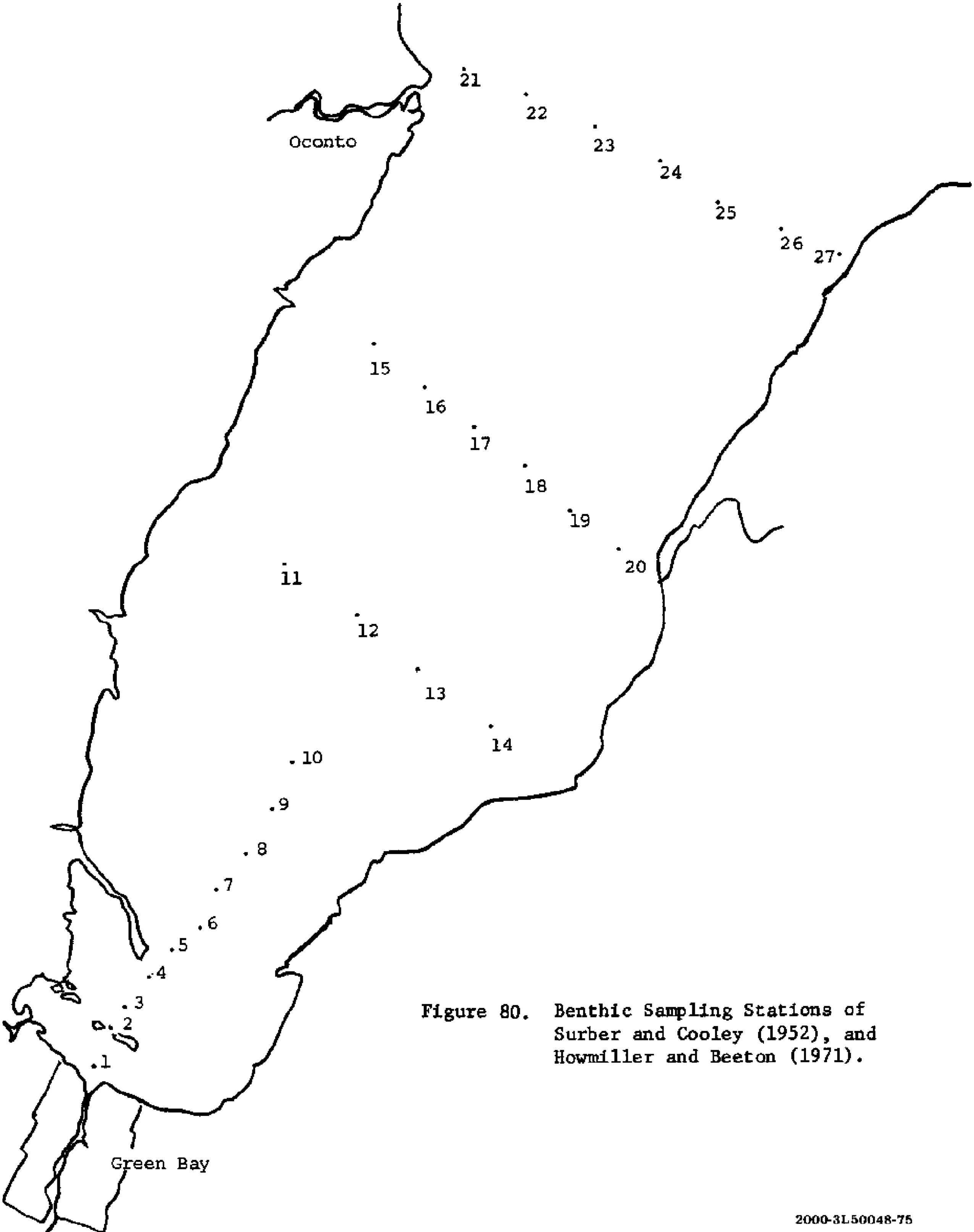

Figure 80. Benthic Sampling Stations of Surber and Cooley (1952), and Howmiller and Beeton (1971).

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