THE UNIVERSITY OF MICHIGAN
Biological Station

Water Quality Studies in the Sleeping Bear Dunes National Lakeshore Region- The Lower Platte River System, Michigan

Technical Report No. 2

JACK E. STOCKWELL
and
JOHN E. GANNON

Douglas Lake

WATER QUALITY STUDIES IN THE SLEEPING BEAR DUNES NATIONAL LAKESHORE REGION - THE LOWER PLATTE RIVER SYSTEM, MICHIGAN[1]

Jack E. Stockwell

and

John E. Gannon

Technical Report No. 2
Biological Station
The University of Michigan
Pellston, Michigan 49769

July, 1975
Reprinted April, 1978

---

[1]This investigation was supported by grant no. TX 400-3-0879 from the National Park Service, and grant no. AEN 72-03483 from the National Science Foundation.

CONTENTS

PREFACE ii

I. INTRODUCTION.............................. 1

II. DESCRIPTION OF STUDY AREA.................. 3

III. METHODS.................................. 13

IV. WATER QUALITY INVESTIGATIONS

Platte River.............................. 17
Platte and Loon Lakes..................... 22
Mud Lake.................................. 34

V. CRITIQUE OF THE MASTER PLAN................ 37

VI. CONCLUSIONS............................... 44

ACKNOWLEDGEMENTS

REFERENCES CITED

WATER QUALITY STUDIES IN THE SLEEPING BEAR DUNES NATIONAL LAKESHORE REGION

The lower Platte River System, Michigan

INTRODUCTION

The scenic Sleeping Bear Sand Dunes area of northwestern lower Michigan recently obtained a National Lakeshore classification from the federal goverment, thereby opening new potential for protection, development and maintenance programs as carried out by the National Park Service.

Baseline water quality data, however, is presently lacking for most of the aquatic resources lying within the boundaries of the new Sleeping Bear Dunes National Lakeshore. To effectively assess the impact that future development will have on existing water quality in this area, it is critical to first have a collection of basic water quality data. Such baseline data should include information on the physical, chemical, and biological characteristics of the lakes and streams; their sensitivity to adverse changes by human impact; and knowledge of watershed features, including the geographical, ecological, and sociological factors that may have a bearing on lake maintenance and management. This is essential knowledge for natural resource managers who will be planning for the wise use and development of these parkland aquatic resources.

Therefore, the objectives of this investigation as undertaken by University of Michigan researchers were to 1) provide baseline limnological data on the aquatic resources of the Lower Platte River region from Platte Lake to the river mouth at Lake Michigan; and to 2) respond to a request from the National Park Service to critique their Master Plan for managment of the Sleeping Bear Dunes region based upon our accrued knowledge of the sensitivity of the parkland's aquatic resources.

DESCRIPTION OF STUDY AREA

The Platte River watershed encompasses an area of 465.2 km^2 (179.6 mi^2). The watershed area within the park boundary is only 32.6 km^2 (12.6 mi^2). Consequently, it is important to note that only seven percent of the Platte River watershed lies within lands under direct control of the National Park Service (Fig. 1). Some of the headwaters of the Platte River are located in Grand Traverse and Leelanau Counties, but Benzie County contains all of the main stream and its major tributaries. The outlet of Lake Ann forms the main branch, which from Lake Ann to Lake Michigan is 40 km (25 mi) long, including entry-to-exit distances across Bronson, Platte[1], and Loon[2] Lakes. The principal tributaries are the North Branch of the Platte River, Carter Creek, and Brundage Creek. Brown (1944) estimated that 48.3 km (30 mi) of tributaries empty into the main branch. Therefore, the Platte River system contains 97 km (60 mi) of streams and rivers of which only about 8 km (5 mi) lie within the National Lakeshore boundary. The main branch is 6.1 to 27.4 m (20 to 90 ft) wide. Usually, a river gradually broadens toward its lower reaches, but Platte River

---

[1] Platte Lake is referred to as "Big Platte Lake" on some maps.

[2] Loon Lake is also known as "Round Lake" on older maps.

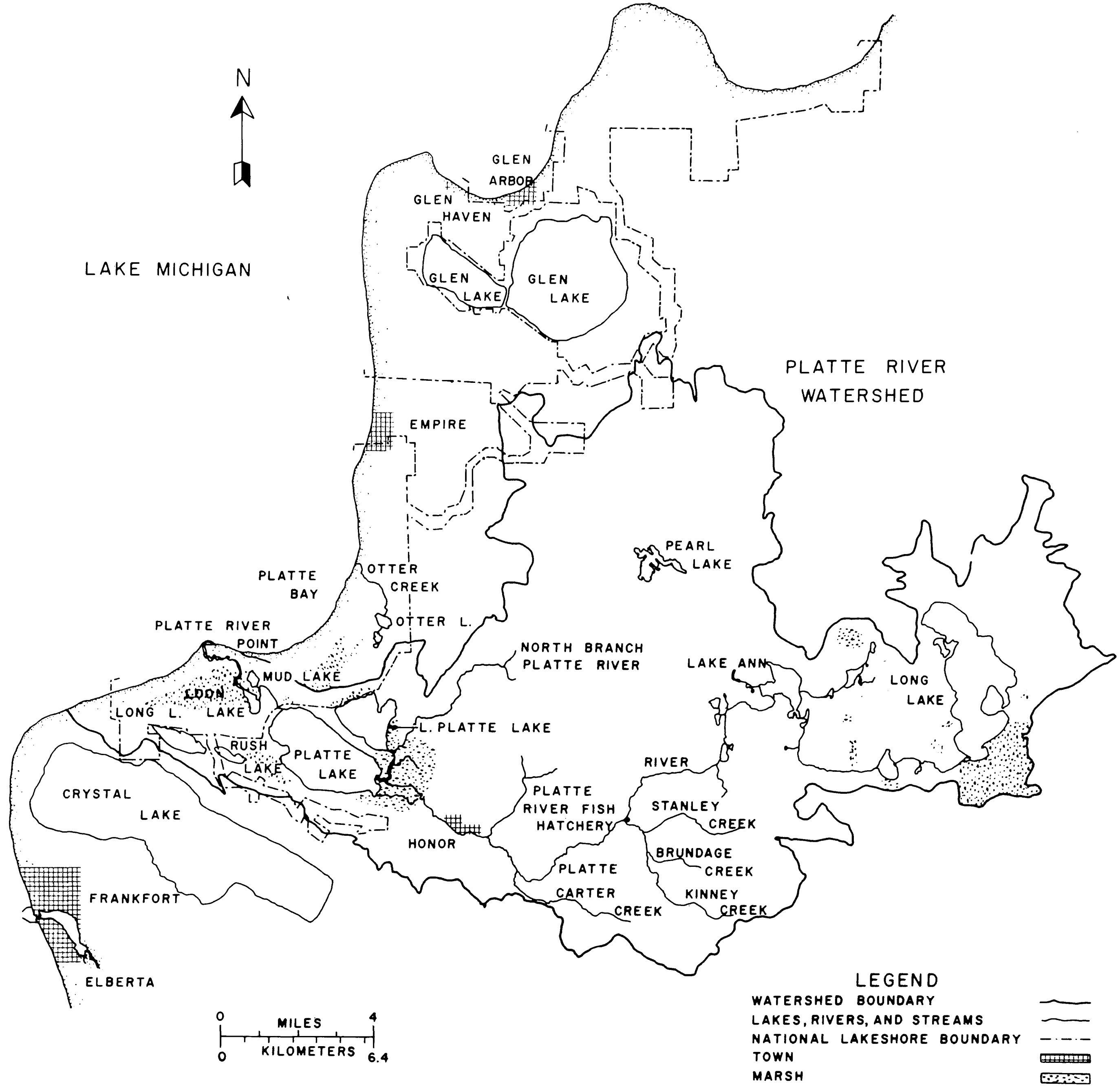

Fig. 1. The Platte River Watershed. Note that only a small portion (seven percent) of the watershed is within

is about as wide and shallow in some places near Lake Ann as it is near its mouth.

The lower Platte River region has a variety of rolling topography due to the history of glaciation in the area (Fig. 2). The basic geological features of the Platte River watershed consist of a)outwash and glacial channels, b) rolling and high moraines,and c) lakes and old lake beds, which occur around the lower third of the river's course (Martin 1955). The drainage basin and adjacent areas have a highly interesting geological history. In fact, its distinctive physiography and scenic quality serve as prime visitor attractions to this region. The Pointe Betsie and Empire moraines which border the lower portion of the Platte River valley are outstanding formations, as is the Sleeping Bear Sand Dune. Sand dunes and other formations such as these within this glacial depression were formed during the Lake Nipissing stage, 4000 years ago. The best beaches were developed in the Algoma glacial stage, 3000 years ago (Dorr and Eschman 1970). The post-glacial lakes that at various times occupied the basin of Lake Michigan influenced greatly the shoreline and inland depression formations found in this area.

The Platte Lake glacial depression contains nine lakes (Fig. 2). Six of the lakes (Little Platte, Platte, Loon, Mud, Long, and Rush Lakes) are drained directly or indirectly by the Platte River, and three (Deer, Bass, and Otter Lakes) are drained by Otter Creek (Fig. 1 and 2). The Platte

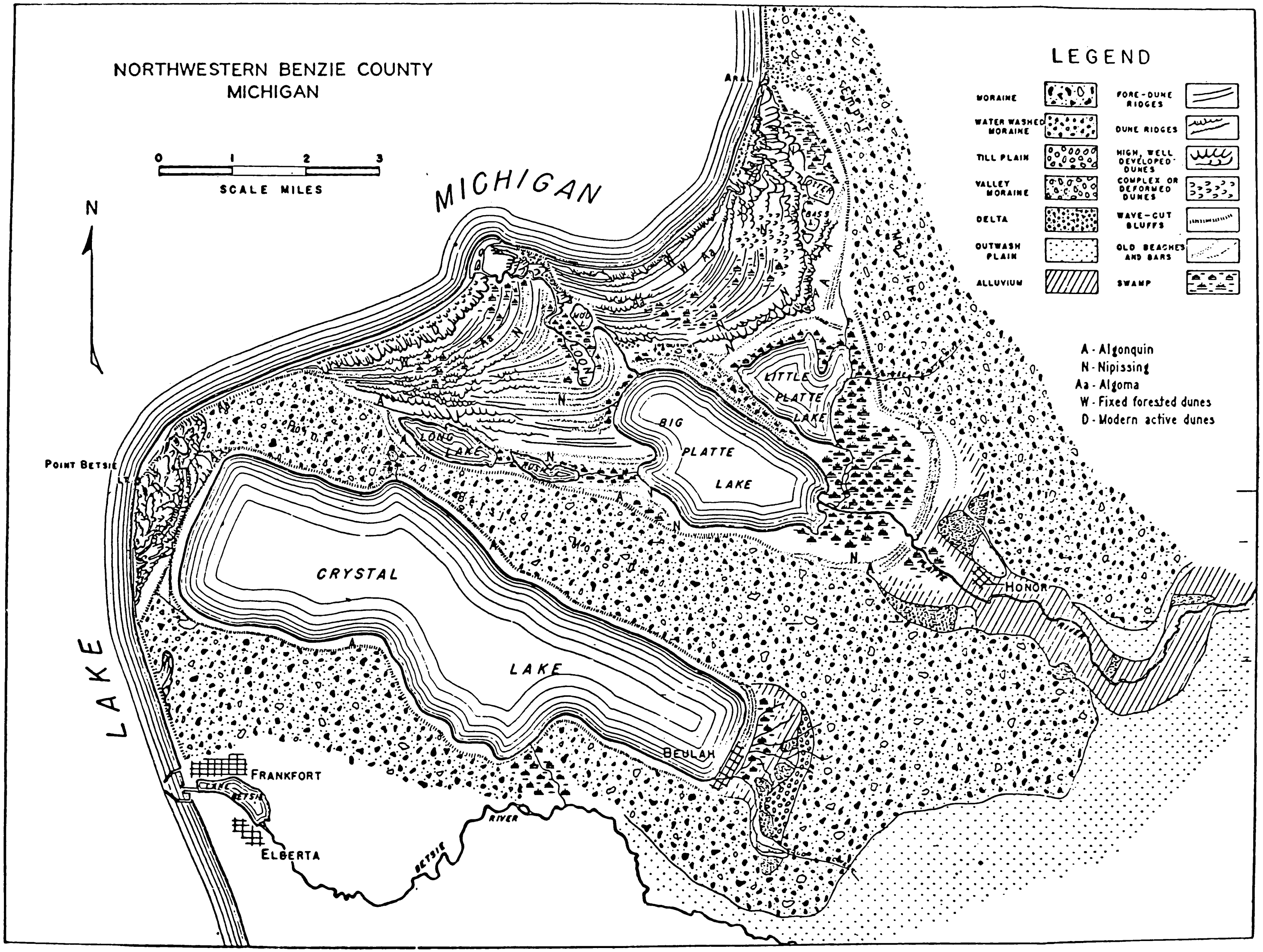

Fig. 2. Geological features of the Platte and Crystal Lake

River enters the Platte Lake glacial depression at Honor and flows northwestward into Platte Lake. About 1.3 km (0.8 mi) northwest of its outlet from Platte Lake, the river is joined by a small creek which is the outlet of Mud Lake. Then Platte River turns abruptly and flows south for nearly 0.8 km (0.5 mi) before entering crescent-shaped Loon Lake. The river's Loon Lake outlet is at the northernmost extension of the lake, and from there the Platte River continues its northerly course to Lake Michigan, a distance of nearly 3.2 km (2 mi). Crystal Lake is not within the Platte Lake glacial depression, but lies in another glacial depression directly south of it (Fig. 2).

Platte, Loon, and Mud Lakes were the focus of our investigation. Platte Lake (Fig. 3) is a large water body, 1,018 ha (2,516 a) with a maximum depth of 27.4 m (90 ft). The lake itself is outside the National Lakeshore boundary, but because of its large size and its location on the Platte River, an investigation of its limnological characteristics was considered important.

Loon Lake (Fig. 4) is located downstream, in close proximity to Mud Lake and within the National Lakeshore boundaries (Fig. 1). It is a small, deep lake 38.4 ha (95 a) in surface area with a maximum depth of 20.1 m (66 ft). Similar to Platte Lake, it lies directly on the course of the Platte River.

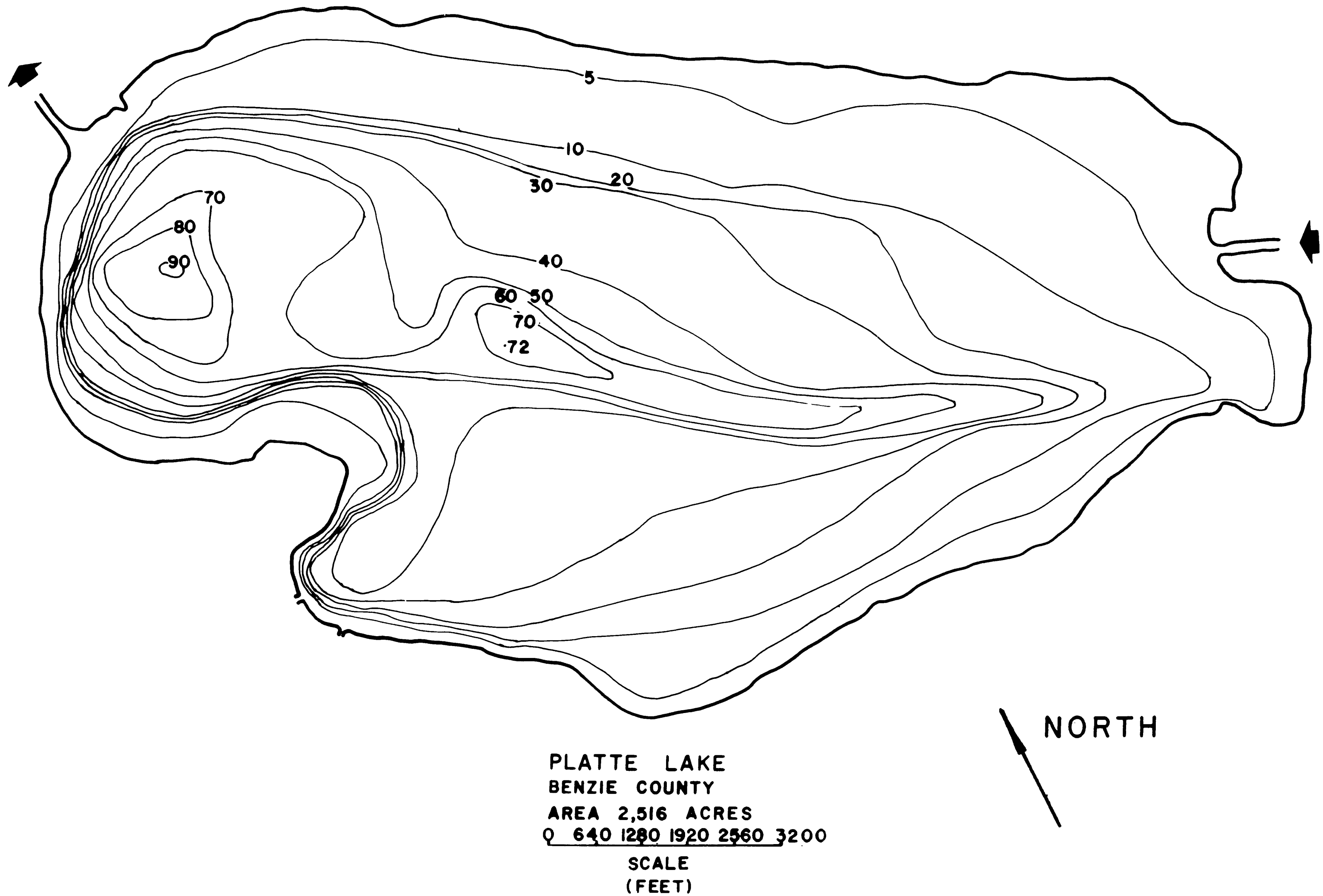

Fig. 3. Morphometric map of Platte Lake.

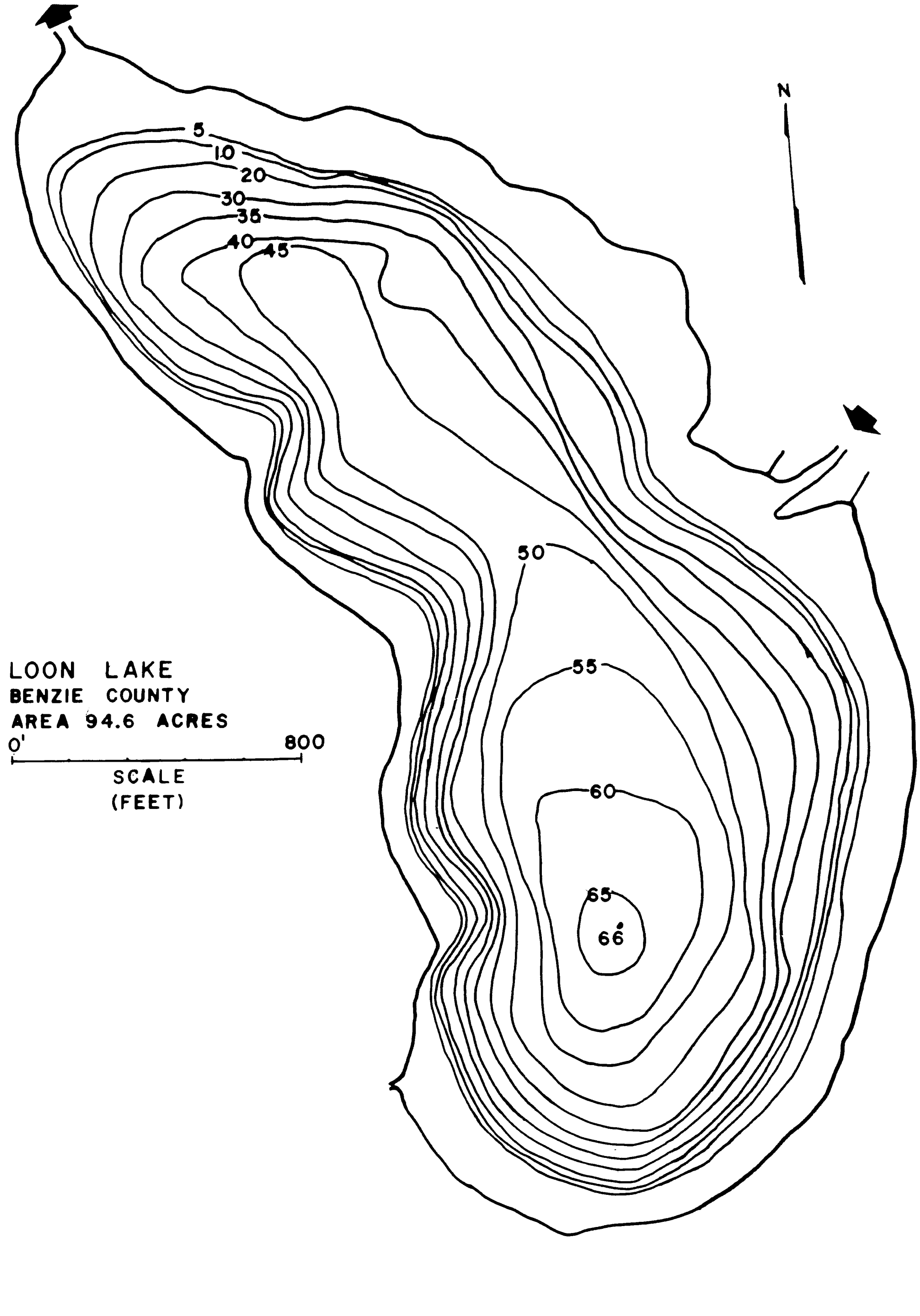

Fig. 4. Morphometric map of Loon Lake.

Mud Lake is also within the National Lakeshore boundaries and is located between Platte and Loon Lakes. It drains into the Platte River by way of a small, sluggish stream known as Mud Creek (Fig. 1). Mud Lake has not been mapped and, consequently, most morphometric data is unavailable. It is small and shallow, consisting of 23.9 ha (59 a) with a maximum depth of only about 0.6 m (2 ft).

The bottom sediments of Platte and Loon Lakes range from sand and fine gravels near shore to soft, flocculent silt in the deepest waters. Mud Lake is aptly named with soft, flocculent, silty muds and partially decomposed plant fragments occurring from shore to shore. The bottom sediments of the Platte River are predominately gravel, followed by sand, silt, and mixtures of these types. There are some patches of clay and others of rubble in scattered locations (Taube 1974).

The superficial soils of the lower Platte River watershed are dominated by sand and gravel almost to the exclusion of other soils. In general, there are gravels in the morainal features, and sand elsewhere. Veach (1953) describes the sands of this region as poor to medium in quality for agriculture.

For the most part, trees and shrubs cover the banks of the Platte River and its tributaries. In some places the river valley as well as adjoining uplands are completely forested. Predominant tree and shrub species differ along the various watershed regions as follows:

<u>Lake Ann to Honor</u>	Primarily aspen, followed by white cedar, hemlock, yellow birch, maple, elm, willow, and tag alder.
<u>Honor to Platte Lake</u>	Primarily tamarack, followed by white cedar, hemlock, and tag alder.
<u>Highway M-22 to the mouth of the Platte River</u>	Primarily tamarack, followed by white pine, red pine, white cedar, and hemlock with tag alder bordering the banks (Taube 1974).

Vegetation in the Mud Lake area consists mostly of swampy lowland vegetation and wooded frontage along its southern border that extends to Loon Lake and a portion of Platte River. This locality has been regarded by the Michigan Natural Areas Council (1970) as one of the best remaining stretches of native undisturbed swamp vegetation.

Extensive tamarack bogs border the western shore of Loon Lake with a ridge and swale complex farther west. Wind-blown sands predominate near the mouth of the Platte River as it encircles sandy Platte Point before emptying into Lake Michigan.

Along most water courses in the lower Platte River region second-home development is prevalent. The shoreline of Platte Lake is extensively dotted with 372 dwelling units, mostly along the northeastern and southern shores. Cabins and cottages line the Platte River from Platte Lake to the M-22 highway bridge. Benzie State Park campground and a private campground are located in the area of the bridge. Also at this point are three liverys for renting canoes for trips downstream to the Platte River mouth. The river bank, from the bridge to Loon Lake, is dotted with cottages and boathouses. Mud Creek and Mud Lake are free of development with the exception of one house trailer on the eastern shore of the lake. Loon Lake has sixteen dwelling units on the east shore and three on the west shore. From Loon Lake to the river mouth there are also cottages along the banks, but not as extensive as in other upstream locations. About 1.6 km (1 mi) from the mouth, there exists a Michigan Department of Natural Resources harvest weir which has been utilized to harvest salmonid fish coming upstream to spawn since 1968.

Lake Township Park is located at the Platte River mouth. This area has been extremely popular for fishing and other recreational activities. It is heavily used as a boat launching and canoe take-out point. There was a restaurant and hamburger stand in the park, however they were recently closed by the National Park Service as part of the transition of the area from private ownership to National Lakeshore.

METHODS

Water samples were obtained at eight stations on the Lower Platte River during November, 1973 and May, 1974 (Fig. 5). Surface samples were obtained at all river stations and in Mud Lake. A series of samples were collected at specific depth intervals at deep central stations in Platte and Loon Lakes.

A three liter capacity Kemmerer water bottle was used to collect the water samples. Samples from each station were placed in 300 ml B.O.D. bottles, pre-washed 8 oz. polyethylene bottles, and ground glass stoppered bottles for later chemical analyses. All bottles were kept covered, away from light, and iced down when warranted.

Temperature profiles were recorded at one meter intervals at the central lake stations using a Whitney resistance thermometer. Light penetration readings were also recorded at the lake stations (except Mud Lake) with a submarine photometer. At all stations secchi disc transparency measurements were recorded.

Water chemistry for dissolved oxygen, alkalinity, and pH parameters were analyzed in the field. The dissolved oxygen determination was carried out titriometrically using the Azide Modification of the Iodometric Method (APHA, 1971. Method 218B, p. 477). Total alkalinity was also determined

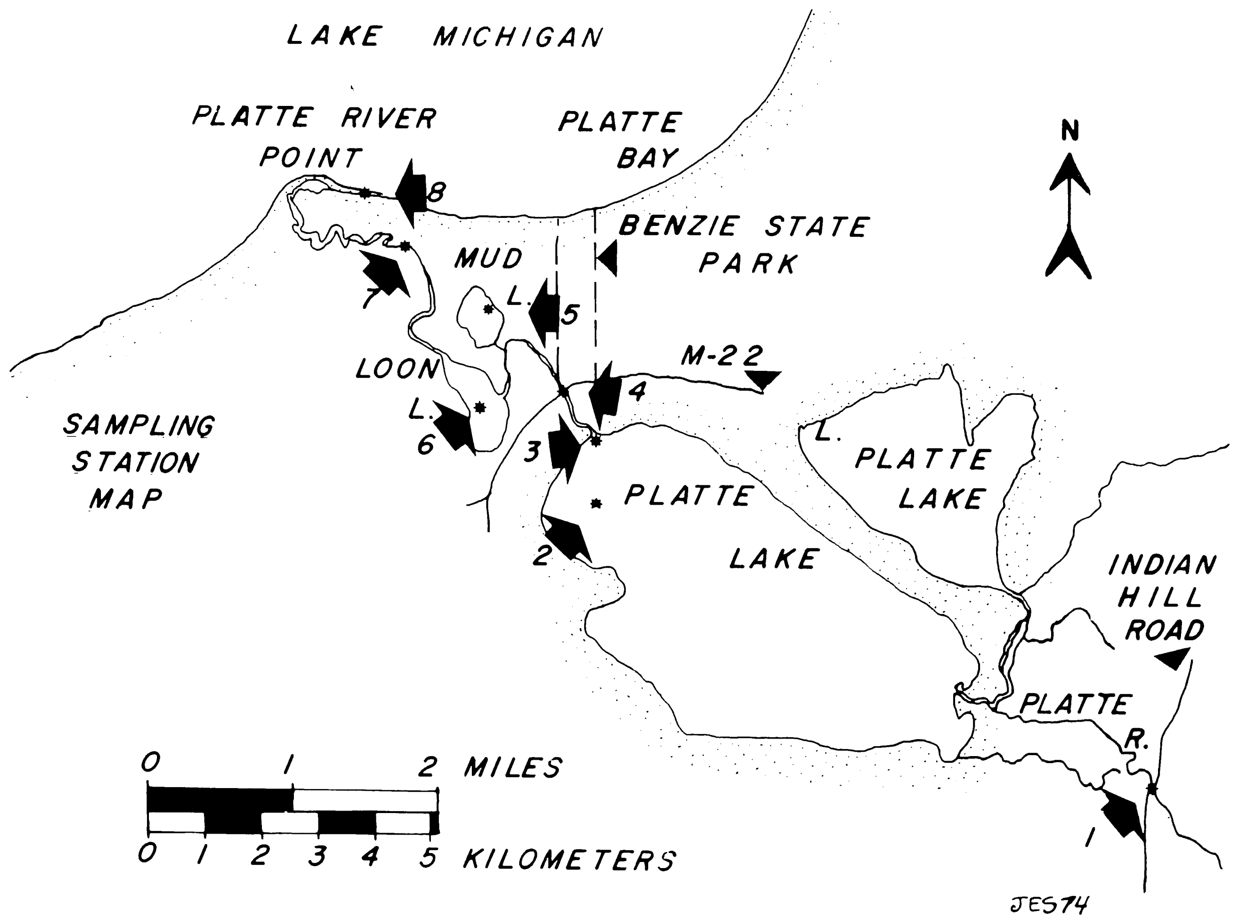

Fig. 5. Locations of water quality sampling stations on the lower Platte River system.

titriometrically using bromocresol green-methyl red mixed indicator solution (APHA 1971. Method 102, p. 52). Field testing of pH was done with a portable Beckman model N pH meter. The remaining chemical parameters were measured in the water chemistry laboratory at the University of Michigan Biological Station. Chloride was measured potentiometrically with a Beckman model H-5 expanded scale pH meter, fitted with a salt bridge and a chloride select - ion electrode (APHA, 1971. Method 203b, p. 377). Total phosphorus and soluble-reactive phosphorus were determined colorimetrically on a Beckman DB-GT Spectrophotometer using a hybrid method of Gales, et al. (1966) for digestion and Schmid and Ämbuhl (1965) for neutralization and color development. Magnesium, sodium, calcium and potassium were determined by atomic absorption spectrophotometry on a Perkin-Elmer Model 305 Atomic Absorption Spectrophotometer (EPA 1971. pp. 102, 112, 115, 118 respectively). Nitrate-nitrogen was determined colorimetrically on the Beckman DB-GT Spectrophotometer (Müller and Widemann 1955). Ammonia-nitrogen was also determined on the Beckman DB-GT Spectrophotometer (Solórzano 1969). Silica was determined colorimetrically on a Beckman DB-GT Spectrophotometer using the Heteropole Blue Method (APHA 1971. Method 151, p. 306).

Plankton tows were collected at all lake stations. A bottom to surface vertical tow using a No. 20 mesh, 1/4 m diameter cylinder-cone plankton net was used at central stations on Platte and Loon Lakes. In the shallow waters of Mud Lake, a horizontal plankton tow approximately 6 m (60 ft) long was used. In addition, a vertical tow sample was taken at a point near Station 7 on the Platte River. The zooplankton samples were preserved in 5% buffered formalin for later analysis in the laboratory.

Water samples were collected at all stations to test for chlorophyll a. Samples were extracted with 90 percent acetone in the field, sealed with parafilm, covered with foil and placed in an ice chest for later determination on a Turner Model III Fluorometer (Strickland and Parsons 1968; p. 201).

WATER QUALITY INVESTIGATIONS

Platte River

Chemical data obtained in both November, 1973 and May, 1974 generally indicated that water quality on the lower Platte River is good (Tables 1 and 2). Dissolved oxygen was near saturation on both dates, indicating that the stream is in a healthy condition. Water throughout the study area was somewhat basic (pH 8.2 - 8.6) and moderately hard (total alkalinity 128-164 mg/ℓ). Ionic constituents were moderately low and generally did not reveal signs of overt pollution (Tables 1 and 2).

An increase in ionic constituents is often noted in a river from its head waters to its mouth. However, such a trend was not observed in the lower Platte River system. Nutrient loading from the village of Honor and/or from the fish hatchery near Honor is possibly indicated by the high nitrogen and phosphorus values at Station 1 above Platte Lake (Tables 1 and 2). Platte Lake acts as a nutrient sink where high concentrations of nitrogen and phosphorus are diluted in the large volume of lake water. They become incorporated into biological systems and are involved in biogeochemical cycling within the lacustrine ecosystem. Loon Lake, further downstream, probably functions similarly as a nutrient sink. Consequently, the presence of lakes along the course of the river prevents a

TABLE 1 CHEMICAL AND CHLOROPHYLL a ANALYSIS OF SURFACE SAMPLES TAKEN AT EIGHT STATIONS ON THE LOWER PLATTE RIVER SYSTEMS DURING NOVEMBER 1973

No.	Station	Temp °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat	pH	Alkalinity mg/ℓ as $CaCO_3$	Conductivity µmhos/cm at 25 °C	Chlorophyll a[1]
1	Platte River (Lake inlet)	4.0	11.69	92%	8.20	164.50	335.00	2.15
2	Platte Lake	5.3	11.21	92%	8.28	141.70	310.00	9.43
3	Platte River (Lake outlet)	4.6	11.75	94%	8.30	145.25	309.00	8.08
4	Platte River (M-22 Bridge)	4.8	11.70	94%	8.28	146.25	309.00	9.43
5	Mud Lake	4.0	11.60	95%	8.30	144.20	306.00	10.78
6	Loon Lake	5.1	11.53	94%	8.36	143.00	229.00	10.78
7	Platte River	5.6	11.85	97%	8.33	153.50	306.00	21.07
8	Platte River (Mouth)	5.2	11.77	96%	8.32	145.00	305.00	6.74

No.	Station	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N µg/ℓ	NO_3-N µg/ℓ	Total P µg/ℓ	SOL - P µg/ℓ	Si mg/ℓ
1	Platte River (Lake inlet)	3.64	0.77	47.34	11.77	55.6	359.4	37.2	30.0	2.8
2	Platte Lake	3.66	0.78	39.87	12.56	24.1	105.1	22.1	15.9	2.4
3	Platte River (Lake outlet)	3.58	0.78	40.18	12.48	35.1	131.6	20.1	15.9	2.7
4	Platte River (M-22 Bridge)	3.65	0.77	40.74	12.42	36.2	127.9	20.1	11.6	2.7
5	Mud Lake	3.58	0.69	39.56	12.31	34.7	110.1	37.2	18.7	2.7
6	Loon Lake	3.74	0.72	40.12	12.49	39.4	95.8	19.0	14.4	1.7
7	Platte River	3.85	0.69	39.56	12.71	49.7	107.6	28.1	15.2	1.7

No.	Station	Temp °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat	pH	Alkalinity mg/ℓ as CaCo	Conductivity umhos/cm at 25 °C	Chlorophyll a[1]	Cl mg/ℓ
1	Platte River (Lake inlet)	17.7	10.02	109%	8.23	135.05	237.66	5.17	3.3
2	Platte Lake	16.72	10.42	109%	8.44	154.00	273.36	3.13	4.7
3	Platte River (Lake outlet)	16.30	10.63	113%	8.43	153.50	311.10	5.06	4.5
4	Platte River (M-22 Bridge)	15.75	10.56	110%	8.43	154.00	313.14	5.95	4.3
5	Mud Lake	18.05	10.55	116%	8.61	128.50	265.20	2.72	4.9
6	Loon Lake	17.0	10.06	107%	8.39	152.50	314.16	4.73	4.5
7	Platte River	17.6	10.44	118%	8.39	151.00	314.16	10.78	4.3
8	Platte River (Mouth)	17.1	9.69	104%	8.28	153.50	316.20	6.12	5.9

No.	Station	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N μg/ℓ	NO_3-N μg/ℓ	Total P μg/ℓ	SOL - P μg/ℓ	Si mg/ℓ
1	Platte River Lake inlet)	2.60	0.65	32.09	10.08	104	184	38	6	2.02
2	Platte Lake	3.84	0.72	40.77	10.69	16	227	6	3	2.68
3	Platte River (Lake outlet)	4.74	0.69	43.60	11.61	19	190	8	2	2.72
4	Platte River (M-22 Bridge)	3.46	0.67	42.18	9.87	23	193	9	4	2.48
5	Mud Lake	3.24	0.62	40.19	8.85	37	61	16	11	0.69
6	Loon Lake	3.16	0.69	36.66	10.30	25	172	16	1	2.61
7	Platte River	3.42	0.65	43.92	10.28	25	172	9	1	2.63
8	Platte River (Mouth)	2.88	0.61	27.68	11.61	46	169	3	7	2.54

[1] calculated in mg/m^3

gradual accumulation of ionic constituents as the river flows downstream.

Chlorophyll a, a measure of phytoplankton standing crop, was moderately low throughout the study area (Tables 1 and 2). Highest concentrations were observed on both dates at Station 7 below Benzie State Park. Nutrient run-off and leaching from the bank area and the public access site downstream from the park may be enhancing phytoplankton productivity in this region. However, more data would be needed before any definite conclusion could be drawn.

Water current speeds (3.3 m^3/sec - 115 cfs) are generally too fast in the lower Platte River to allow euplanktonic organisms to exist. Considerable wash-out of phytoplankters and zooplankters can be expected at the outlets of Platte and Loon Lakes. Although these tychoplankters may not be able to grow and reproduce in the turbulent waters of the river, they nevertheless wash downstream in considerable numbers, where they provide food for benthic macroinvertebrates and young fish. The zooplankton sample taken at Station 7 on the Platte River in May contained most species of rotifers and microcrustaceans found in abundance in the plankton of Loon and Platte Lakes (Table 3). Such washout of plankton can be significant in enhancing productivity of benthos and fish in the river downstream from these lakes.

The Platte River has been studied to a certain extent in relation to benthic macroinvertebrates by Hildebrand (1971)

TABLE 3 ZOOPLANKTON OF THE LOWER PLATTE RIVER SYSTEM IN NOVEMBER (N), 1973, AND MAY (M), 1974.

RELATIVE ABUNDANCE OF EACH TAXON IS DESIGNATED BY THE FOLLOWING SYMBOLS:

* - ABUNDANT	X - PRESENT
+ - COMMON	R - RARE

STATION	PLATTE LAKE		LOON LAKE		MUD LAKE	LOWER PLATTE RIVER
DATE	N	M	N	M	M	M
ROTIFERA						
Asplanchna priodonta			R			
Collotheca mutabilis	R					
Conochilus unicornis	+	+	R	X	X	X
Filinia longiseta		*		X		X
Gastropus stylifer	X		R		X	
Kellicottia longispina	X	X	X	X		X
Keratella cochlearis	R	X	+	X	+	*
Keratella crassa	*		*			
Keratella earlinae	*	*	*	*		+
Keratella quadrata		+		X	X	X
Notholca labis	R					
Polyarthra dolichoptera		X		X		
Polyarthra major	R		X			
Polyarthra rumata	+		+			X
Polyarthra vulgaris	+	+	*	X	X	X
Synchaeta pectinata			X			
Synchaeta stylata	+	X	X	X	+	X
COPEPODA						
Calanoida						
Diaptomus oregonensis	X			X		
Diaptomus ashlandi			X			
Diaptomus reighardi					+	
Diaptomus spp. immature	X				+	X
Epischura lacustris		+	X	X	X	X
Cyclopoida						
Cyclops bicuspidatus thomasi	X	X	X	+	X	
Cyclops vernalis	X	+	X	X	X	X
Mesocyclops edax					X	

(continued)

Thirty-six taxonomic groups of aquatic invertebrates were found. The observation of Trichoptera and Ephemeroptera indicates good water quality. Chironomidae and Oligochaeta having a wide range of tolerances were also encountered. Overall, the aquatic invertebrate list indicates that water quality in the river is generally good, with no overt problems existing.

The Platte River and Platte Bay areas feature excellent fishing resources. In fact, fishing in the river has always been excellent, with many species being encountered (Table 4). Since the yearly planting of Coho and King salmon began in 1966 and 1971 respectively, the Platte Bay has also emerged as a prime area. Both the Platte River and the Platte Bay presently receive heavy fishing pressure. Field estimates by Department of Natural Resources personnel set weekend use of the Platte Bay launch site at 900 craft a day, with 200 launching per week day during the month of September, 1967 (Department of Natural Resources, 1973). Such recreation carried out in these great numbers is and will be putting great pressure on facilities in the Platte River mouth area.

Platte and Loon Lakes

Since Platte and Loon Lakes are located in close proximity to one another on the same river, it seems warranted to discuss them together.

TABLE 4 FISHES COLLECTED IN THE PLATTE RIVER DURING 1967-1972 WITH GENERAL ASSESSMENTS OF ABUNDANCE. (from Taube, 1974)

KEY TO SYMBOLS FOR ABUNDANCE:

N - NUMEROUS
C - COMMON
F - FEW
R - RARE
X - ABUNDANCE NOT ESTABLISHED

SPECIES	ABUNDANCE	SPECIES	ABUNDANCE
BROWN TROUT	N	ROSYFACE SHINER	F
RAINBOW TROUT	N	COMMON SHINER	F-C
BROOK TROUT	F	BLUNTNOSE MINNOW	F
COHO SALMON	N	WHITE SUCKER	F-C
CHINOOK SALMON	F	BULLHEAD spp.	R
CHESTNUT LAMPREY	X	BROOK STICKLEBACK	R
SEA LAMPREY	X	SMALLMOUTH BASS	F
CISCO	R	LARGEMOUTH BASS	R
RAINBOW SMELT	R	PUMPKINSEED	R
CENTRAL MUDMINNOW	F	BLUEGILL	R
NORTHERN PIKE	R	ROCK BASS	F
CARP	R	YELLOW PERCH	F
CREEK CHUB	F-C	LOGPERCH	F-C
BLACKNOSE DACE	C-N	MOTTLED SCULPIN	C-N
HORNYHEAD CHUB	F		

Although Platte Lake is 26 times larger than Loon Lake in surface area, the two lakes share many similar morphometric features (Table 5). Both lakes are moderately deep inland lakes. Platte Lake is deeper (maximum depth 27.4 m/90 ft) than Loon Lake (20 m/66 ft), but their mean depths are nearly identical (8.4 m/27.5 ft and 9.0 m/29.5 ft respectively). Both lakes lack prominent bays, points, and other shoreline projections and therefore have low values for the shoreline development factor (1.29 and 1.32 respective In general, lakes with higher shoreline development factors have greater potential for over-use by humans because they have longer shorelines relative to the surface area of the lakes. Also, lakes with larger shoreline development factors are naturally more productive due to the presence of shallow, protected embayments.

The flushing rate or water renewal time for a lake is an important parameter in determining the sensitivity of a lake to change by human impact. The amount of time it takes to flush out the existing volume of lake water and replace it with in-flowing water is known as the flushing rate. Lakes with fast flushing times (rapidly flowing influent and effluent streams) can usually maintain higher water quality conditions in the face of adverse human impact than can lakes with slow flushing times. A rough calculation of the flushing rate for a lake can be made by dividing the lake volume by the flow rate at the outlets. Using flow data

TABLE 5 MORPHOMETRIC DATA FOR PLATTE AND LOON LAKES
BENZIE COUNTY, MICHIGAN

PARAMETER	PLATTE LAKE	LOON LAKE
Maximum depth	90 ft (27.4 m)	66 ft (20 m
Mean depth	27.5 ft (8.4 m)	29.5 ft (9.0m
Maximum length	8,950 ft (2,728 m)	1,506 ft (459 m
Mean width	6,416 ft (1,946 m)	1,127 ft (343.3m
Surface area	2,516 a (1,019 ha)	95 a (38.5 ha
Volume	$30.00x10^8 ft^3$ ($85.00x10^6 m^3$)	$1.22x10^8 ft^3$ ($3.45x10^6 m^3$
Shoreline length	48,025 ft (14,638 m)	9,512.5 ft (2,899 m
Volume development factor	0.92	1.34
Shoreline development factor	1.29	1.32

from Taube (1974) for the Platte River below Platte and Loon Lakes, we obtained flushing times of 302 days for Platte Lake, and 12 days for Loon Lake. These are relatively rapid flushing times, as such calculations would be expressed in ye for many inland lakes in Michigan. As further means for comparison, the flushing rate of lakes Erie and Michigan have been estimated as 3 and 100 years, respectively. The rapid flushing times for Platte and Loon Lakes may be a most important factor in maintaining good water quality conditions in these lakes in spite of nutrient loading from upstream areas and heavy cottage development on the Platte Lake.

During the November, 1973 sampling period, both lakes were in the fall overturn period of their annual thermal cycle with temperatures uniformly cold throughout the water column (Fig. 6). Light transparency was moderately good with secchi disc depths of 3.5 m (11.5 ft) and 4.0 m (13.1 ft recorded for Platte and Loon Lakes, respectively. The light compensation depth or depth of one percent light transmittanc usually defines the limits of plant growth in lakes. The zone of active photosynthesis in Platte and Loon Lakes extended from the surface to the conpensation depth of 7 m (23 ft) and 8 m (26.3 ft), respectively.

Both Platte and Loon Lakes were in the early stages of thermal stratification during the May, 1974 sampling period (Fig. 6). Light transparency as measured with a secchi disc

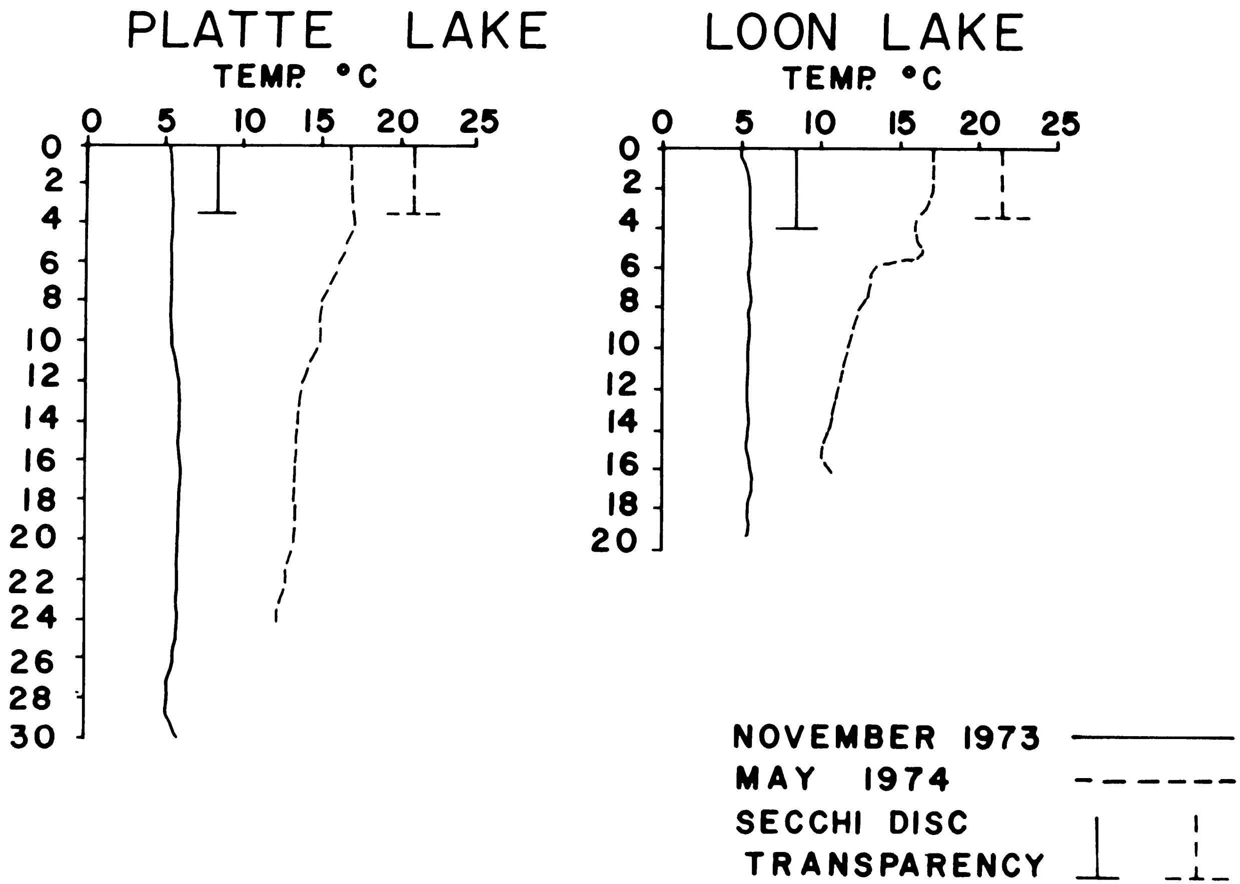

Fig. 6. Temperature profiles and secchi disc transparency for Platte and Loon Lakes during November, 1973 and May, 1974.

was similar in both lakes to that in November, 1973. The zone of active photosynthesis was to 10 m (32.8 ft) in Platte Lake and to 7 m (23 ft) in Loon Lake during May, 1974.

Chemical data obtained in both November, 1973 and May, 1974, indicated that Platte and Loon Lakes are moderately hard water lakes with generally healthy water quality characteristics (Tables 6 through 9). Both lakes are moderately hard (total alkalinity 140-160 mg/ℓ and specific conductance 229 - 318 μmhos/cm at 25°C). Dissolved oxygen conditions were near saturation throughout the water column in both lakes during the study periods. Some oxygen depletion was recorded only from the bottom waters of Loon Lake during May, 1974. It is suspected that this trend would continue with oxygen depletion occurring throughout the hypolimnetic waters of Loon Lake during summer. Nutrient concentrations, as well as phytoplankton standing crops as measured by chlorophyll a were moderately low and generally indicated that Platte and Loon Lakes are in good water quality condition (Tables 6 through 9).

A total of 27 species of Rotifera and Crustacea were recorded in the zooplankton of Platte Lake during the study periods, while 29 species were observed in Loon Lake (Table 3). Since the two lakes are in close proximity to one another on the same river, it is not surprising to note that 24 of these species were common to both lakes. Undoubtedly, more species would be recorded for these lakes if data from

TABLE 6 CHEMICAL AND CHLOROPHYLL *a* ANALYSES AT A CENTRAL STATION IN PLATTE LAKE DURING NOBEMBER, 1973

Depth (m)	Temp. °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat.	pH	Alkalinity[1]	Conductivity[2]	Chlorophyll *a*[3]	
Surface	5.3	11.21	92%	8.28	141.70	310.00	9.43	
15	5.5	12.38	96%	8.28	142.75	308.00	-----	
29	5.3	11.31	93%	8.23	145.00	310.00	-----	

Depth (m)	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N µg/ℓ	NO_3-N µg/ℓ	Total P[4]	Sol P[5] -	Si[6]
S	3.66	0.78	39.87	12.56	24.1	105.1	22.1	15.9	2.4
15	3.76	0.78	40.49	12.29	39.4	134.2	19.3	9.6	2.4
29	3.69	0.76	40.37	12.39	37.1	136.7	21.2	13.0	2.6

[1]calculated in mg/ℓ as $CaCO_3$
[2]calculated in µmhos/cm at 25 °C
[3]calculated in mg/m³

[4]calculated in µg/ℓ
[5]" " " "
[6]calculated in mg/ℓ

TABLE 7 CHEMICAL AND CHLOROPHYLL *a* ANALYSES AT A CENTRAL STATION IN PLATTE LAKE DURING MAY, 1974

Depth (m)	Temp. °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat.	pH	Alkalinity[1]	Conductivity[2]	Chlorophyll *a*[3]	Cl mg/ℓ
Surface	16.72	10.42	109%	8.44	154.00	273.36	3.13	4.7
5	16.79	10.38	110%	8.44	153.75	278.46	3.34	4.0
10	15.05	10.30	106%	8.38	154.50	309.06	4.17	4.7
15	13.61	9.89	99%	8.32	156.00	313.14	5.56	5.2
24	13.03	9.83	96%	8.22	153.00	315.18	11.18	5.2

Depth (m)	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N µg/ℓ	NO_3-N µg/ℓ	Total P[4]	Sol-P[5]	Si[6]
S	3.84	0.72	40.77	10.69	16	227	6	3	2.68
5	4.84	0.71	39.87	12.12	21	227	6	4	2.47
10	4.24	0.68	42.61	10.38	24	188	23	9	2.77
15	4.64	0.65	41.67	10.38	29	232	10	4	2.62
24	4.84	0.72	37.04	10.28	33	216	11	6	2.68

[1] calculated in mg/ℓ as $CaCO_3$
[2] calculated in µmhos/cm at 25 °C
[3] calculated in mg/m³
[4] calculated in µg/ℓ
[5] " " " "
[6] calculated in mg/ℓ

TABLE 8 CHEMICAL AND CHLOROPHYLL *a* ANALYSES AT A CENTRAL STATION IN LOON LAKE DURING NOVEMBER, 1973

Depth (m)	Temp. °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat.	pH	Alkalinity[1]	Conductivity[2]	Chlorophyll a[3]
Surface	5.1	11.53	94%	8.36	143.00	229.00	10.78
10	5.5	11.45	93%	8.42	145.00	305.00	-----
15	5.5	11.49	93%	8.43	140.00	304.00	-----
19	6.5	11.31	95%	8.45	145.00	309.00	-----

Depth (m)	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N µg/ℓ	NO_3-N µg/ℓ	Total P[4]	Sol - P[5]	Si[6]
S	3.74	0.72	40.12	12.49	39.4	95.8	19.0	14.4	1.7
10	3.74	0.73	39.56	12.62	43.1	92.4	19.0	18.7	1.5
15	3.38	0.75	40.18	12.71	49.7	103.4	19.3	15.2	1.9
19	3.68	0.75	40.49	12.48	40.1	109.2	19.4	17.1	1.5

[1] calculated in mg/ℓ as $CaCO_3$
[2] calculated in µmhos/cm at 25 °C
[3] calculated in mg/m^3

[4] calculated in µg/ℓ
[5] " " "
[6] calculated in mg/ℓ

TABLE 9 CHEMICAL AND CHLOROPHYLL *a* ANALYSES AT A CENTRAL STATION IN LOON LAKE DURING MAY, 1974

Depth (m)	Temp. °C	Dissolved Oxygen mg/ℓ	Dissolved Oxygen % sat.	pH	Alkalinity[1]	Conductivity[2]	Chlorophyll *a*[3]	Cl mg/ℓ
Surface	17.00	10.06	107%	8.39	152.50	314.16	4.73	4.5
4	15.80	10.10	106%	8.20	152.00	283.56	4.17	4.7
7	13.06	10.39	103%	8.42	158.50	316.20	5.56	4.3
11	11.30	9.44	90%	8.13	153.00	318.24	5.06	4.6
16	10.65	7.38	68%	7.94	156.00	317.22	7.39	4.1

Depth (m)	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	NH_3-N µg/ℓ	NO_3-N µg/ℓ	Total P[4]	Sol P[5]	Si[6]
S	3.16	0.69	36.66	10.38	25	172	16	1	2.61
4	2.88	0.74	35.50	9.97	24	186	17	5	2.58
7	3.46	0.67	43.21	10.69	24	197	15	5	2.52
11	4.64	0.68	45.65	10.49	54	186	16	5	2.72
16	4.44	0.68	39.74	9.67	148	182	23	3	4.00

[1]calculated in mg/ℓ as $CaCO_3$
[2]calculated in µmhos/cm at 25 °C

[4]calculated in µg/ℓ
[5]" " "

mid-summer would have been available. Nevertheless, some inferences to the zooplankton community structure and its relation to water quality can be made for the two lakes.

Platte Lake was characterized by the presence of 23 species of zooplankton in November, 1973 and 16 species in May, 1974 (Table 3). Twelve species of Rotifera were collected during November, while nine were observed in May. *Keratella crassa*, *K. earlineae*, *Conochilus unicornis*, *Synchaeta stylata*, and several species of *Polyarthra* were predominant in fall, while *Filinia longiseta*, *K. earlinae*, *K. quadrata*, *C. unicornis*, and *P. vulgaris* were most prevalent in spring. *Filinia longiseta* and *K. quadrata* have been reported as indicators of eutrophy (Pejler 1957). The crustacean zooplankters in Platte Lake were represented by eleven species in November and seven species in May (Table 3). Calanoid copepods were low in diversity, with *Epischura lacustris* abundant only during May. Cyclopoid copepods were equally low in diversity with the eutrophic species *Cyclops vernalis* most prevalent in both sampling periods. This species is characteristic of eutrophic waters throughout the Great Lakes region. Four limnetic Cladocera were collected from Platte Lake along with one littoral species, *Alona rustica*. *Bosmina longirostris* and *Holopedium gibberum* were most abundant in both sampling periods. *Chydorus sphaericus* was present during both sampling periods. High numbers of both *B. longirostris* and *C. sphaericus* are often indicative of eutrophic conditions. High abundance of only the former species was recorded for Platte Lake.

The composition of zooplankton in Loon Lake was similar to that in Platte Lake, both in terms of diversity and relative abundance of species. Those species most abundant during a given sampling period in one lake were usually abundant at the same time in the other lake. The only significant exception was *Cyclops vernalis*. This species was present during both sampling periods in Loon Lake, but *Cyclops bicuspidatus thomasi* was more abundant, especially in May.

A trend has been noted in many lakes where calanoid copepods are more abundant relative to cladocerans and cyclopoid copepods in oligotrophic lakes. Conversely, cladocerans and cyclopoid copepods become more abundant relative to calanoid copepods in eutrophic lakes (Gliwicz 1969; Gannon 1972). Calanoid copepods in both Platte and Loon Lakes were strikingly less abundant relative to the other micro-crustacean groups during both sampling periods. Consequently, both zooplankton community structure and the presence of indicator species suggest that Platte and Loon Lakes are tending toward eutrophy.

Mud Lake

Unfortunately, Mud Lake has not been mapped, so morphometric data is unavailable. The lake is aptly named as it is an extremely shallow body of water with silty muds predominating the sediments. Encroaching swampland vegetation surrounds the lake. These features indicate that Mud Lake is in late stage hydrach succession. Limnologically, Mud Lake is radically different from Platte and Loon Lakes.

A water chemistry sample was obtained only from Mud Lake Creek at its confluence with the Platte River during November, 1973. Chemical data obtained at this station are nearly identical with those obtained at all lower Platte River stations, and obviously reflect mixing of Mud Lake Creek and Platte River waters (Table 1).

A central station in Mud Lake was sampled during May, 1974 (Table 2). The waters of Mud Lake are less hard than all other lower Platte River stations including Platte and Loon Lakes. The shallow waters of the lake were supersaturated with dissolved oxygen undoubtedly due to phytoplankton photosynthesis. Alkalinity and specific conductance were approximately 63% and 58% lower in Mud Lake compared to other stations. Nutrient concentrations were all lower in Mud Lake than in other stations. Swamp vegetation surrounding the lake likely acts as a filter by taking up nutrients from water seeping into the lake from its surrounding watershed.

Zooplankton composition in Mud Lake was considerably different from that found in Platte and Loon Lakes (Table 3). Since Mud Lake is so shallow, a truly limnetic zone is almost non-existent. Consequently, eulimnetic zooplankters are poorly represented in the lake. Only six species of rotifers were reported, with *Keratella cochlearis* and *Synchaeta stylata* most abundant. The eutrophic indicator *K. quadrata* was also present. Fifteen species of micro-crustacean zooplankton were observed in the lake, but several of these are littoral forms usually collected only incidently in open water. *Diaptomus reighardi*, a calanoid copepod common in the eutrophic waters of western Lake Erie, was the most prevalent calanoid copepod in Mud Lake. Four species of cyclopoid copepods including the eutrophic indicator *Cyclops vernalis* were present, but all were in low numbers. *Bosmina longirostris* was the most abundant cladoceran. Undoubtedly more species of Rotifera and Cladocera would have been reported for this lake if the littoral vegetation had been sampled.

CRITIQUE OF THE MASTER PLAN

The second objective of our study was to critique the original Master Plan for development of the Sleeping Bear Dunes National Lakeshore (National Park Service 1970). Comments which follow are based upon our investigations and observations of the inland aquatic resources in the Sleeping Bear Dunes region.

All lakes and rivers should not be treated the same in terms of their potential to withstand human development. Some water bodies are more sensitive to human development than others. Those lakes and rivers deemed sensitive to development should be managed so that minimal human impact occurs. Wise development of the region should proceed on those water bodies which are deemed least sensitive to change by human impact.

The degree of sensitivity of a water body to adverse change by human impact is not simple to determine. All lakes and streams are different in many subtle ways, just as each human being is uniquely different from all others. The metabolism of lakes and streams is an integrating function of all physical, chemical, and biological factors operating within the system. Sensitivity must be determined from detailed studies on the limnology of the water body itself, coupled with knowledge of watershed characteristics. The boundaries of the watershed, as well as soil types, land-use patterns, and human population characteristics within the watershed must be determined.

The aquatic resources within the lakeshore boundary consist of one river, one creek, and two small lakes. The total surface area of these lakes and streams is small in comparison to the land area within the lakeshore boundary. In general, water quality of these aquatic resources is good. Wise planning is essential to the preservation of good water quality in the face of increasing human use of the region.

Knowledge of soil types in lake and stream watersheds has become a valuable land-use planning tool in recent years. Soil characteristics are often more important than geographic location in planning a development. Some soils have moderate to severe limitations for many recreational uses. Soils with steep slopes (greater than 12 percent) have high potential for erosion. Soils that are saturated with water for long periods of time exhibit slow permeability rates and slow drainage rates which place severe limitations on development. Disposal of domestic sewage is commonly attempted using on-lot soil absorption fields which function as reverse drains or subsurface irrigation systems. Some soils are capable of handling excess water from drain fields and others cannot. Construction of sewage disposal systems without prior soil evaluation can often cause serious health and environmental problems (Bartelli _et al_. 1966). Soil information as well as current water quality data should be consulted when planning any development adjacent to lakes and streams in the Sleeping Bear Dunes National Lakeshore.

It is important to reiterate here that only seven percent of the surface area of the Platte River watershed lies within the lakeshore boundary. The preservation of long-term environmental quality in the Sleeping Bear Dunes region will depend on wise land-use planning not only within the Lakeshore boundary, but throughout Benzie County as well. National Park Service personnel should be encouraged to cooperate with state and county natural resource managers in developing environmentally sound land-use planning policies in the Platte River watershed.

Water quality on the lower Platte River depends largely upon the quality of water in Platte Lake. Because of its large surface area, large volume, and rapid flushing characteristics, Platte Lake is currently in good water quality condition in spite of heavy second home development on its shores. The National Park Service should cooperate with Michigan Department of Natural Resources personnel in maintaining a water quality monitoring program on Platte Lake in order to detect early sign of incipient eutrophication.

The lower Platte River is one of the prime aquatic attractions in the Sleeping Bear Dunes region. The semi-wild character of the river must be maintained while providing recreational facilities for park visitors. Plans for expanding the Benzie State Park area should be viewed with caution. Soil conditions in that region may limit expansion of environmentally sound development there. Canoe trips from the M-22 highway bridge probably should be continued. The use of canoes on the river should be monitored, however, to discern the need for possible limitations on the number of canoes on the river at any given time. It is well known from experiences on other popular Michigan canoeing rivers that both the quality of the recreational experience and the environment suffer when too many canoes are used on a short stretch of river at the same time.

The potential for development around Mud Lake is poor due to wet soil conditions. Consideration should be given to managing Mud Lake as a natural area. Development of picnic grounds on the shore of Mud Lake may be desirable. The lake is too small and shallow for motorboats, but it is presently a popular sojourn for canoeists on their way downriver from the M-22 highway bridge. The canoes enter Mud Lake from Platte River by way of Mud Lake Creek and exit the same way. If there were picnic grounds constructed on the southeast shore of the lake, it would greatly enhance the recreational potential of the area. With the presence of Lake Michigan Road along the eastern edge of Mud Lake, the picnic area would serve the needs of both water and land travelers.

Water quality in Loon Lake is good and is expected to remain so because of the rapid flushing characteristics of this small lake on the Platte River. Loon Lake has encroaching shrubs and swampy vegetation unsuitable for development around most of its shores. The only exception is along the southern shore where a number of cottages occur. This area would be an excellent picnic grounds with a public access site. The access should not have a vehicle ramp, but should accomodate craft that can be carried down to the water. This would encourage small boat use on Loon Lake for fishing and reduce larger motorcraft use on the lake and adjacent stretches of river.

Heavy recreational pressure from fishing, picnicking, and swimming has focused on the Platte River mouth for many years and will undoubtedly continue. The natural resource manager will have a difficult task in trying to provide adequate recreational facilities in this region while still maintaining the beautiful but environmentally fragile integrity of the river mouth. The original Master Plan (National Park Service 1970) called for a marina and parking lot complex in this area. The State Department of Natural Resources attempted to develop a marina and parking lot for 400 cars, but the plan was abandoned in the face of public opposition. The river mouth should continue to be managed as a public access site for motorboats and as a take-out point for canoes. Swimming and picnic facilities should be expanded. However, too much congestion will occur if too many people and vehicles are allowed to funnel into the river mouth area. Separate swimming and picnicking facilities should be constructed further down the shoreline. This will alleviate some of the people and vechile pressure at the river mouth public access site. Nevertheless, parking conditions are far from adequate at the access site and pose a difficult problem in development of this region. In addition, Williams and Works, Inc. (1973) stated that soil and water table conditions in the Platte River mouth area are such that on-site sewage disposal facilities could easily malfunction and cause health and environmental problems. They suggest that a sewer system will be needed to handle the large volume of waste expected to be generated by heavy human use of the area

In order to alleviate human impact on the river mouth itself, an alternate site for a marina and parking area, north along the shore of Platte Bay, was proposed by the National Park Service (1970). The proposal was studied by the Michigan Department of Natural Resources and deemed to be much more costly, less functional, and at least as objectionable environmentally (Gazlay 1974). Williams and Works, Inc. (1973) examined this area and found poor soil and water table conditions for the construction of an on-site sewage disposal system. It appears that only long-range planning can solve the marina and parking dilemma in this environmentally sensitive region.

Hiking, bicycling, and nature trails have been proposed for the Sleeping Bear Dunes National Lakeshore. These types of recreational developments should augment public enjoyment of the region without adversely affecting the area's aquatic resources. We suggest that construction and maintenance of such trails be carefully planned and executed. Trail heads and scenic over-looks should have adequate comfort facilities, thus alleviating the need for such facilities along the trails.

In summary, the feasibility study for development of the Sleeping Bear Dunes National Lakeshore conducted by Williams and Works, Inc. (1973) repeatedly emphasized limitations to development in the regions with poor soil and high water table conditions. It would be advisable to closely follow the suggested recommendations in that study for on-site water and sewage disposal facilities. Soil conditions of the region are an important aspect to be considered before proceeding with any development. A detailed soil survey for Leelanau County is presently available. Modern soil surveys should also be undertaken for Benzie County.

Lakes and streams within the lakeshore boundary will undoubtedly be heavily utilized for recreational activities as the parklands becomes developed. It is most important that a regular water quality monitoring program be instituted for these lakes and streams.

CONCLUSIONS

The inland aquatic resources of the Sleeping Bear Dunes National Lakeshore within the study area consist of the lower Platte River and its associated lakes (Loon and Mud), and Otter Creek. Environmental quality of the lower Platte River region is generally good today. However, sound long-range land-use planning will be necessary to safeguard environmental quality in the face of increased human impact in the future. Such planning must not be limited to just the lakeshore boundary. It is most important to note that the Platte River watershed encompasses parts of three counties, but only seven percent of the drainage basin lies within the lakeshore boundary.

The water quality of the Platte River within the lakeshore boundary is in good condition, as determined by chemical analyses and observations of biological indicator organisms. High concentrations of nitrogen were noted at the inlet to Platte Lake, indicating that nutrient loading from the village of Honor and/or the Platte River fish hatchery was occurring. Such conditions, if allowed to continue, could adversely affect water quality in the Platte River within the lakeshore boundary.

Platte Lake lies outside the National Lakeshore Boundary. However, future environmental quality of the lower Platte River system within the park depends largely upon continually maintaining a healthy condition for this strategically located lake. Platte Lake has remained in generally good water quality condition in spite of extensive cottage development on its shores. The rapid flushing characteristics, large surface area, and large volume of the lake have been important in maintaining its good water quality in the face of human impact. Biological communities in Platte Lake were generally indicators of mesotrophic conditions. However, the presence of the eutrophic zooplankters *Cyclops vernalis*, *Filinia longiseta* and *Keratella quadrata* suggest that the lake may be tending toward eutrophy. Platte Lake undoubtedly acts as a nutrient sink for the inflowing waters of the upper Platte River. This is an important factor in safeguarding long-term environmental quality on the lower Platte River system.

Water quality in Loon Lake is expected to remain good, even in the face of future increased human impact. The lake has extremely fast flushing characteristics which should keep it in relatively good condition even if water quality in the lower Platte River should decline somewhat. As in Platte Lake, Loon Lake appears to be mesotrophic with a few indicators of eutrophy in the zooplankton. Development of a picnic area and public access for carry-down boats seems feasible for Loon Lake.

Mud Lake is a shallow water body in late stage hydrach succession. Swampy vegetation around most of the lake acts as a sponge, absorbing many of the nutrients which seep toward the lake through its watershed. Long-term water quality in this region will largely depend upon maintaining wetlands vegetation around the lake in a natural state. The Mud Lake area should probably be managed as a wild area with a possible picnic site, especially for canoeists, along its eastern shore.

The Platte River mouth region poses a real problem for the natural resource manager. It enjoys extreme popularity for recreational pursuits on one hand, yet is environmentally sensitive to adverse change by human impact on the other. Separation of swimming and picnicking facilities from the public access site seems desirable. Development of expanded marina and parking facilities does not appear feasible in the face of public opposition. In addition, on-site sewage disposal at the river mouth is not recommended due to poor soil and high water table conditions.

Natural resource managers have a difficult task in providing recreational facilities for the people while still maintaining quality in environmentally fragile lands and waters. It is critically important that a quality recreational region be used but not abused, developed but not destroyed. Through continued research and environmental monitoring of the lands and waters of the Sleeping Bear Dunes National Lakeshore, and by consideration of recommendations set forth in previous studies, the Lakeshore can be a scenic area of natural beauty while providing high quality recreation and aesthetic enjoyment for many years to come.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of the following University of Michigan Biological Station staff in making this investigation possible: Richard Stemberger for field assistance and coordination and analyses of rotifer data; Bill Foster and Mary Vanderlaan for field assistance; Carol Minard, Gerry Krausse, and Kevin Carter for water chemistry analyses; Mary Beth Pattyn and Kathyrn Bricker for crustacean zooplankton analyses; and Ole Lundin for assistance with morphometric data. Jan Nagel assisted in manuscript preparation. We also wish to thank Max Holden, J. A. Martinek, and Charlie R. Parkinson of the National Park Service for their cooperation in this investigation.

REFERENCES CITED

American Public Health Association. 1971. Standard methods for the examination of water and wastewaters. 13th ed. APHA, New York. 874 p.

Bartelli, L. J., A. A. Klingebiel, J. V. Baird, and M. R. Heddleson (Eds.). 1966. Soil surveys and land use planning. Soil Sci. Soc. Amer. and Amer. Soc. of Agron. 185 p.

Brown, C. J. D. 1944. Michigan streams -- their lengths, distribution and drainage areas. Mich. Dept. of Conserv., Inst. Fish. Res. Misc. Publ. No. 1. 21 p.

Calver, J. L. 1948. The glacial and past glacial history of the Platte and Crystal Lake depressions, Benzie County, Michigan (Part 2). Mich. Geol. Survey, Lansing. 172 p.

Dorr, J. A., and D. F. Eschman. 1970. Geology of Michigan. Univ. of Michigan Press, Ann Arbor, Mich. 476 p.

Environmental Protection Agency. 1971. Methods for chemical analysis of water and wastewaters. Analytical Quality Control Laboratory, Cincinnati, Ohio. 312 p.

Gales, M. Jr., E. Julian, and R. Kroner. 1966. Method for quantitative determination of total phosphorus in water. J. Amer. Waterworks Assn. 58: 1363.

Gannon, J. E. 1972. Effects of eutrophication and fish predation on recent changes in zooplankton Crustacea species composition in Lake Michigan. Trans. Amer. Microsc. Soc. 91: 82-83.

Gazlay, A. G. 1974. Recommendation to Natural Resources Commission on Platte River area harbor. Mich. Dept. of Natural Resources. Mimeo. 6 p.

Gliwicz, Z. M. 1969. Studies on the feeding of pelagic zooplankton in lakes with varying trophy. Ekol. Polska 17A: 663-708.

Goodnight, C. J. 1973. The use of aquatic macroinvertebrates as indicators of stream pollution. Trans. Amer. Microsc. Soc. 92: 1-13.

Hildebrand, S. G. 1971. The effect of Coho spawning on the benthic invertebrates of the Platte River, Benzie County, Michigan. Trans. Amer. Fish. Soc. 100: 61-68.

Martin, H. M. 1955. Map of the surface formation of the southern peninsula of Michigan. Michigan Department of Conservation, Geol. Surv. Div. Publ. No. 49.

Michigan Natural Areas Council. 1970. The preservation of natural features in the Sleeping Bear National Lakeshore. Mimeo. 10 p.

Michigan Department of Natural Resources. 1970. Water quality of selected lakes and streams in the Grand Traverse Bay region. Mich. Water Resour. Comm. 94 p.

Michigan Department of Natural Resources. 1973. Environmental impact statement: Developing harbor-of-refuge mooring facilities and launching facilities at the mouth of the Platte River, Lake Township, Benzie County. Waterways Division, Mich. Dept. of Natural Resources. 35 p.

Müller, R. and O. Widemann. 1955. Nitratbestimmung in Seewasser. Jahrbuch V. Wasser 22: 247-271.

National Park Service. 1970. Master plan for Sleeping Bear Dunes National Lakeshore, Michigan. U. S. Dept. of Interior. National Park Service. 53 p.

National Park Service. 1974. Wilderness study for Sleeping Bear Dunes National Lakeshore, Michigan. U. S. Dept. of Interior. National Park Service. 27 p.

Pejler, B. 1957. Taxonomical and ecological studies on planktonic Rotatoria from central Sweden. Kungl. Svenska, Vetenskapskad. Handl. Fjärde Ser. 6: 1-52.

Schmid, M. and H. Ämbuhl. 1965. Die bestimmung geringster Mengen von Gesamtphosphor in Wasser von Binnenseen. Schweiz. Z. Hydrol. 27: 184-192.

Solórzano, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr. 14: 799-801.

Strickland, J. D. H. and T. R. Parsons. 1968. A practical handbook of seawater analysis. Fish. Res. Bd., Canada. Bull. No. 167. 311 p.

Taube, C. M. 1974. A descriptive and historical account of the Platte River, its surrounding area, and its salmonid fishes. Michigan Dept. Nat. Res., Fish. Div. Fish. Res. Rept. No. 1809. 88 p.

Veach, J. O. 1953. Soils and land of Michigan (with soil map of state). Michigan State Coll. Press. E. Lansing, Mich. 241 p.

Williams and Works, Inc. 1973. Feasibility study for regional water and sewer systems, Sleeping Bear Dunes National Lakeshore, Michigan. 46 p.