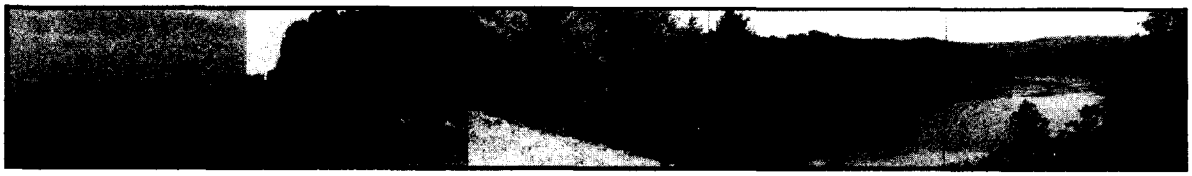
DUNE-POCKETED WETLANDS



along the
Eastern Lake Michigan Shoreline

December 1987

vital resources, inc.

DUNE-POCKETED WETLANDS

ALONG THE

EASTERN LAKE MICHIGAN SHORELINE

Prepared for

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Geological Survey Division, and
Land and Water Management Division

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by

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I. INTRODUCTION

The sand dunes of eastern Lake Michigan are recent and dynamic geologic features. They developed upon the framework of the glacially-formed landscape, and concurrently with the youthful drainage systems of Michigan, to produce a unique and attractive shoreline. In order to understand the present ecology of the dunes, and their relationships with other ecological communities within the shoreline zone, particularly the wetlands associated with the dunes, it is necessary to examine the processes involved in the formation of these interlocking systems and subsystems.

Many previous studies of the dunes have dealt with specific issues or areas rather than with the entire shoreline. Some have focused on dune ecology and vegetation processes (e.g. Wells and Thompson, 1975 et seq). Others have looked at the process of Lake Michigan dune development (Cressey 1928, Scott and Dow 1937, Tague 1946, Olson 1958, etc.). Some more recent studies have concentrated on mapping and inventorying the dunes (Powers 1958, Kelley 1962, MDNR 1976, MDNR 1978, Buckler 1979, MNFI 1986). Management of the dunes as separate ecosystems was legally addressed within Michigan in 1976 by enacting the Sand Dune Management and Protection Act (Michigan PA 222). Resulting from this Act was the establishment of a set of Designated Sand Dune Areas occurring within two miles of the shoreline. This procedure provided an ecologically arbitrary though legally definitive landward boundary beyond the limits of the high dunes for many shoreline dune areas.

In 1978, the barrier sand dunes were outlined within these areas. The landward boundary of the Barrier Dunes was defined as "the most landward base of the first sand dune formation from the Great Lake Shoreline which displays the greatest relative relief within a designated sand dune area". Based upon Buckler's 1979 study, a set of barrier dunes was inventoried and classified as legally defined above.

Many of the studies of the dunes have been limited to the area defined as Barrier Dunes. Recent ecological studies in the Nordhouse Dunes system (Wells and Thompson 1984, Hazlett 1987, Goff et al 1986, 1987) have included land further inland as part of the dune system, mainly because the area was under consideration for wilderness protection. In Goff et al's Environmental Study (1986) and Supplement (1987) a "landward dune-pocketed wetlands" zone was identified as an integral part of the dune system. The interrelationship between the dunes and the landward wetlands became a central issue in the Supervisor of Wells' decision to limit hydrocarbon development in the Nordhouse Area (Guyer, 1987): "the barrier dune formation and associated dependent lands is an example of an ecosystem type that is unique in its process of development and in the structural and functional relationships among land units....the confined natural hydrologic systems identified within the Nordhouse Dunes Area are of critical importance to the maintenance of a valuable wetland and associated surface water environment."

The Nordhouse Dunes issue focused attention on the importance of ecologically defining the landward limit of the dune system. The 1987 Supplement to the Nordhouse Environmental Study suggested that "a more complete survey of dune associated wetlands, considering the effects of barrier dune formation on upgradient drainage patterns, is needed before the degree and significance of ecological uniqueness of the Nordhouse dune-pocketed wetlands can be determined." In the course of the studies on the Nordhouse Dunes System it became apparent that the outer boundary of the abutting dune-pocketed watershed defines a logical and defensible dune ecosystem zone. Figure 1 is a reproduction of the surface watershed divides recognized in that study.

An advantage of using the watershed boundary for defining the dune system is that it includes all associated wetlands. These are ecologically important subsystems, rich in species and high in productivity. Numerous plants, birds, fish, amphibians, insects and mammals thrive in these wet areas. Wetlands also act as water purifiers by allowing silt, sediment and other impurities to settle out and by chemically transforming what they receive from surrounding uplands. In the case of "pocketed wetlands", surface water contamination anyplace in the watershed may concentrate in the catchment along the base of the dunes[1].

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[1]Under still air conditions, heavier air contaminants (e.g. hydrogen sulfide gas) would also settle into the catchments of these pocketed watersheds, concentrating air borne toxic materials at the base of the dunes.

Figure 1. Surface watersheds of the Nordhouse Dunes area. Drainage patterns from the eastern watershed divide to the base of the dunes can be seen in dark tones of lowland vegetation (from Goff et al, 1987)

BD = Barrier Dunes (Lake Michigan)
LL = Lost Lakes
PC = Porter Creek
DPW = Dune-Pocketed Wetlands
(n) northern unit
(s) southern unit
HL = Hamlin Lake

Although both sand dunes and wetlands are protected by respective laws, there has been little systematic examination of the interaction or developmental relationships between them. Ecological and hydrologic relationships between the dunes and wetland areas lying behind the dunes have hardly been considered. Where these two important resources, dunes and wetlands, intermingle, they should be studied and managed as a system, rather than as isolated features. Wetlands and sand dunes are two of the states most valued resources, and establishing a link between them gives these areas added significance. The present study contributes to that understanding by examining the formation processes and physiographic relationship of shoreline drainage systems and by providing an inventory and a series of maps of landward dune-pocketed wetlands.

Because of the presence of dunes which have blocked their flow to the big lake, many of the watersheds along the shoreline have not developed the deeply cut stream channels typical of unimpeded streams with watersheds of a similar size. Several of these undeveloped watersheds remain pocketed behind the dunes. Other deeply cut drainage systems have also been pocketed, apparently more recently. A hypothesis of this study is that the history of shoreline drainage systems can be reconstructed by correlating the pattern and degree of their development with post glacial lake shoreline chronology, with particular reference to dune formation. Additionally, we will examine evidence that suggests that some presently unimpeded stream drainage systems were formerly blocked or "pocketed" behind dunes that have been removed by rising lake levels. Specific objectives of the study include:

1. To describe the processes that have resulted in the formation of the drainage systems of the eastern Lake Michigan basin, especially those that are associated with shoreline dunes.

2. To generally classify, describe, and inventory by type the drainage systems of the eastern Lake Michigan shoreline.

3. To more specifically map, describe and inventory all dune-pocketed wetlands of the eastern Lake Michigan shoreline.

II. METHODS

The study area stretches along the eastern Lake Michigan shoreline from the Michigan/Indiana border north to the Straits of Mackinac. The counties included are Berrien, Van Buren, Allegan, Ottawa, Muskegon, Oceana, Mason, Manistee, Benzie, Leelanau, Antrim, Charlevoix, and Emmet. Most of the effort was concentrated on the area between the Indiana/Michigan state line and Frankfort in Benzie County. North of this, crustal rebound becomes an increasingly dominant factor and the dune-drainage system linkage is more obscure.

Much of the study was conducted in the laboratory examining maps and various sources of information in order to identify and classify wetland areas within a zone along the shore, especially those behind sand dunes. A representative series of dune-associated wetland drainage systems was inspected in the field to describe the vegetation and collect other relevant information. Field studies were for the purpose of understanding and defining the types of shoreline drainage systems and related wetlands, rather than for comprehensive ecological inventory. Field work was followed by further map studies, literature review, glacial and recent geomorphological process reconstructions, and data analysis. The resulting classification was used to inventory the shoreline drainage systems based mainly on drainage patterns and topography.

II.A Initial Map Analysis

Our initial task was to identify all nearshore wetlands and catchments. A set of USGS topographic maps covering the shoreline was used to identify lakes, ponds and wetland areas. The first criterion applied was the presence of marsh or aquatic symbols on the topographic map within two miles of the shoreline. Some low-lying areas not mapped as wetlands but shown as unforested, and judged to be possibly seasonally wet, were also included. The topographic maps range in age from 1970 to 1983, and are divided into two scales at Muskegon (1:24,000 south and 1:25,000 north). They were sufficient for identifying many of the wetland catchment areas and lakes, but were considered not detailed enough to use as the sole source of information.

The National Wetlands Inventory, conducted by the USDOI -- Fish and Wildlife Service was consulted, but this survey has completed only portions of two counties within our study area so it was not available as a consistent information base. These data were used where available. The USDA -- Soil Conservation Service provided detailed soil surveys of nine of the thirteen counties included in the study area. For the surveyed counties, the location of wet and mucky soils was added to the topographic base map. Hydrologic information was noted. In addition, land cover/use maps available from the MDNR -- Division of Land and Water Management, were consulted to help identify wetlands. In most instances these proved to be too general to be useful for the purposes of this study. Drain commissioners in several of the counties were interviewed by phone and drain maps were obtained for several southern shoreline areas. A set of nearshore wetlands was identified using these sources of information.

In order to determine which of the nearshore wetlands were associated with dunes, we overlaid the designated sand dune and barrier dune maps available from the MDNR (1976, 1978) onto the USGS base maps with shoreline wetland catchments and lakes designated. Some of these wet areas occurred in conjunction with dunes, but were not included in the designated or barrier dune areas. To augment the shoreline dune designation, we used the state-wide dune distribution map (Kelley, 1962). Both the designated sand dune and barrier dune map series (MDNR 1976, 1978) were compared with Kelley's map. In addition, the USGS quadrangle maps were used to identify all areas of high relief along the shoreline that might be of dune origin. In sandy areas with high hills, the Michigan glacial geology map by Farrand (1982) was consulted to make a general distinction between dune sand and materials of other origin. This information was compared with the soil survey reports. It was possible, by studying all of these sources, to determine practical limits for all shoreline dune areas. We were liberal in identifying sand dunes, considering most nearshore sandy areas with high topographic relief as dunes. We then determined which of the wetland catchment areas initially identified abut against sand dunes on their lakeward side. Those that do, we considered dune-associated wetlands.

The next step of the survey was to delineate the watershed boundaries of all identified dune-associated wetland areas. The watershed divides provide a more definitive basis for defining the natural system limits than does simply distance from the shoreline. The watershed areas were delineated on the USGS topographic base maps by studying the contour lines.

II.B Aerial Photo Interpretation

Within the watershed boundary we defined the upland, lowland, and catchment components of the system. These distinctions were made from aerial photographs using stereoscopic infrared imagery at the scale of 1:24,000 available from the MDNR. Each watershed was examined, and, based on the structure of the vegetation and relief patterns of the land, these three land classes were differentiated. Catchment basins include open water areas, emergent aquatic beds, marshes, shrub carrs, and other non-forested areas. In many of the watersheds a distinct change in vegetation structure could be detected between the catchment and the surrounding lowland. Lowlands are usually forested areas on relatively flat topography associated with the catchments. The boundaries of these were usually indicated quite accurately on the topographic maps, but they were confirmed by photo interpretation and by field checking in some instances. Uplands are the portion of the watershed from the boundary of the flat lowlands to the watershed divide.

Initially, the areas of the watersheds and of their upland, lowland, and catchment components were estimated by copying the map of each onto paper of consistent weight and then cutting out the areas. Each piece was weighed on a precise balance and the areas were calculated using the weight of a known area of the same paper. Later measurements made use of a dot grid or square grid.

II.C Ownership and Disturbance

The ownership patterns of the sites was also included for management reference. Using the most recent plat maps available at the State of Michigan Library a determination was made between private, state or federal ownership, or a combination. This data was expressed as a percentage of the watershed area. A planimeter projecting machine was used to bring the maps to scale, and then the procedure described above (cutting out the areas and weighing them or counting a dot grid) was used to calculate acreage by ownership class.

Information for the estimation of the degree of human development within each area was taken from the USGS topographic maps. Information from field inspection and plat maps was also included. The scale and criteria used are shown in Table 1.

Table 1. Degree of development scale. Numerical values were assigned as follows to each dune-pocketed wetlands watershed to rate disturbance. The lowland/catchment was combined and received a disturbance value of L = 0 to 10. The upland was assigned a value of U = 0 to 10. Because disturbance in the lowland/catchment area is considered more significant, it was given twice the weight in calculating a weighted mean disturbance for the watershed as a whole. The watershed disturbance index, W = [(L x 2) + U] / 3, was calculated using the scaling criteria listed below.

	Lowland/Catchment	Upland	Watershed
Major Dev.	10	10	W = [(L x 2) + U] \ 3
Moderate Dev.	7	7	
Minor Dev.	3	3	
No Apparent Dev.	0	0	

Major Development -- Impacts which greatly affect drainage (e.g. ditches, dams, or extensive roadways), water quality (e.g. extensive agriculture, city storm drains), or have great potential for other adverse impacts (sand mining, hydrocarbon drilling, sewage treatment plant)

Moderate Development -- Impacts which have less physiographic or water quality effects, but increase traffic and detract from aesthetics (e.g. county or state roads, railroads, small towns, campgrounds, etc.)

Minor Development -- Small-scale impacts which have a minor effect on the ecological quality of the area, but may increase traffic or detract from aesthetics (e.g. individual or few houses, trail roads, powerlines, etc.)

II.D Field Inspections

Many of the map and aerial photo procedures were undertaken concurrently with the field inspections. As soon as the domain of dune-associated wetlands was identified, an initial set of candidate areas for field examination was selected. Field sites were chosen to represent both the dune-pocketed wetlands and other shoreline wetland types that we wished to differentiate from dune-pocketed wetlands. Inspections began in the areas close to the Nordhouse Dunes. These were reconnaissance level examinations to assist in the development of the classification and inventory. Detailed studies of the sites were not possible within the time constraints of this project. We limited reconnaissance site examinations to a central portion of the shoreline from Bar Lake Swamp on the north to the Fruitvale Dunes area on the south because this zone appeared to be representative and appeared to contain the greatest diversity of shoreline wetland drainage system types. At each site we made systematic observations at one of three levels of intensity.

Level I: General Scouting -- The purpose of this level of observation was to gain general impressions of the wetland watershed areas by driving perimeter roads or hiking through each area scouted. Notes on drainage, topography, soils, cover types and development were made and referenced to the USGS topographic maps. Significant features were documented by narrative field notes and photography.

Level II: -- Specific Site Description -- The purpose of this level of observation was to locate a predetermined candidate site of interest (e.g. a catchment basin, drainage divide, upgradient wetland, etc.) and describe its characteristics. Photos were taken in most instances. A narrative description was written to summarize the area's significance. Vegetation cover type was noted and dominant species were recorded. Initially, based on the hypothesis that certain variables would prove to be important in distinguishing and understanding these wetlands, each was ranked subjectively on three scales using vegetation community composition and other indicators: (A) a mineral enrichment scale [0 = ombrotrophic to 10 = minerotrophic], (B) a closure/succession scale [0 = open water to 10 = lowland forest], and (C) a surface water variability scale [0 = constant seasonal water level to 10 = highly variable water level between early spring and late summer]. The basis of these scales is described more fully in the "Wetland Vegetational Processes" section of this report (Section IV).

Level III -- Vegetation/Species Survey -- This level of observation was made for certain sites that seemed to typify the wetland drainage type classes. It consisted of a Level II observation plus a species search within the general location of the identified site. Rather than keying unknown species on site, they were collected, labeled and later pressed and identified. Vegetation summaries of several of the representative sites examined in the field are presented in Appendix I.

II.E Extended and Refined Map Analysis

We found it necessary to map all watershed divides within the shoreline zone in order to adequately delineate and understand the limits of the dune-pocketed wetlands watersheds. From the Michigan/Indiana state line northward to Portage Lake in Manistee County, every drainage area and watershed along the shoreline was delineated, assigned a number, and named. Because watersheds and drainage basins are naturally hierarchical and vary in scale, our ability to recognize them was dependent on the degree of detail presented on the topographic maps. In this sense, the entire study is scale dependent, but the concepts developed can be applied at a more specific level as more refined topographic information becomes available. For the purposes of a statewide inventory, the USGS quadrangle sheets provide an adequate level of detail. In areas having relatively high relief the boundary designation was straightforward. In flatter areas, there was often a degree of uncertainty as to where the divide line should be placed due to the width of the contour interval (generally 10 feet or 3 meters). Delineation of the boundary in these areas was more difficult and often somewhat arbitrary, especially where artificial drainage has altered the landscape. Many of the mapped watershed boundaries extended inland well beyond the two mile limit initially established. We mapped them back from the shoreline a sufficient distance to assure that every point on the landscape had been included in one of the watersheds or drainage areas. From the topographic maps and other map sources, each section of the shoreline was ranked on the basis of the extent of dunes [0 = no evidence of dunes; s = slight dune development; m = moderate dune development; h = highly developed dunes].

II.F Classification of Shoreline Drainage Systems

All drainage systems associated with shoreline dunes were grouped into natural classes on the basis of the process of their origin. This was a procedure of reflective dialogue -- making educated speculations about the process of formation of each drainage basin, particularly its relationship to dunes, and then determining its membership within one of the classes that we had hypothesized. During this stage of our work, we repeatedly re-examined the topographic maps with watersheds designated, consulted the field data, and reviewed literature sources. If one of the drainage systems did not seem to fit the classification, we adjusted our concept of the natural classes and worked back through the entire set of mapped watersheds. We went through several iterations of this process, finally arriving at a necessary and sufficient natural classification of all shoreline dune associated drainage systems.

II.G Screening, Ordination, and Classification of Dune-Pocketed Wetlands Drainage Systems

The criteria for each shoreline drainage system class, based on the process of origin of its members, permitted us to screen out all but the dune-pocketed wetlands drainage basin class. Eighteen dune-pocketed wetlands watershed systems were recognized. Each example of this class was characterized in terms of size, extent of upland, lowland, and catchment, topographic relief, ownership, and disturbance.

A simple watershed area/topographic relief ordination was prepared and patterns of distribution of the dune-pocketed watersheds were interpreted. Finally a classification of dune-pocketed watersheds was developed by delineating natural clusters within the ordination having similar drainage pattern features. A general hypothesis regarding the development process separating the major types is presented. This is based on literature review and reconstruction of likely historical geological sequences employing topographic data and hydrologic theory.

II.H Preparation of Reference Maps

Using the USGS topographic sheets as a base, a set of drainage basin maps was prepared. From the Indiana/Michigan State Line northward to Frankfort (Benzie County) these covered all streams draining to Lake Michigan as well as shoreline direct drainage areas. All dune-pocketed wetlands watersheds were included. In the area north of Frankfort, where more recent glaciation and crustal rebound has altered drainage patterns, we listed only the first order stream watersheds. Characterizations of the systems containing dune-pocketed wetlands is given in Section V, and the listing of all watersheds and drainage areas is given in Appendix II. The maps of dune-pocketed wetlands drainage systems are presented as Appendix II in a form suitable for digitizing and entry in the Michigan Resource Information System.

III. EASTERN LAKE MICHIGAN SHORELINE LANDSCAPE FORMATION PROCESSES

Four principle agents have altered the surface geologic landscape of Michigan: 1) glacial ice; 2) running water; 3) waves and shore currents; and 4) wind. Within the last 15,000 years, each of those forces has acted on the present shoreline area of eastern Lake Michigan to produce an interesting and unique coastal landscape. This report presents a classification of the dune-associated drainage systems of that shoreline. It also identifies, analyses, and inventories a new landscape type -- the dune-pocketed wetlands watershed type. In order to understand these systems, it is essential to consider the processes that formed them. A large body of literature has developed since the late 1800's on the history of Michigan's landforms and the processes of their development. The following is a brief description of how the four primary agents of landscape development have effected the eastern Lake Michigan shoreline, with specific regard to development of dune-pocketed wetlands drainage systems. We also describe some of the vegetational processes that are important to the formation of plant communities within dune-associated wetlands.

III.A Glacial Processes

The work of continental glaciation upon North America began approximately a million years ago during the Pleistocene epoch.

The ice age was brought about by a radical change in world climate, the cause of which is still open to speculation. During this time there were several glacial advances and retreats over the Great Lakes region. At the peak of each advance, the ice was as much as two to three miles thick. The tremendous weight of this ice mass caused the earth 's crust to be temporarily pressed downward. As the ice melted back, the crust slowly rebounded.

As a glacier advanced, it cut deep basins in the areas where the bedrock was weakest, and deposited the eroded material on top of the stronger areas as it melted back. This process of repeated erosion and deposition scooped out the Great Lakes basins and formed the undulating upland landscape of Michigan. The present character of the Lake Michigan shoreline began to be formed with the last major glacial advance. This glacier separated the Lake Michigan basin from the other Great Lakes and forced drainage to the south through the Chicago River. The northwestern section of the lower peninsula was considerably altered by this advance. The ice cut many deep north-south trending lakes and bays (Torch Lake, Elk Lake, Traverse Bay) and also left many kettle lakes throughout the area. The effects of glaciation on drainage are very pronounced in this region. The area was also more effected by crustal rebound. Therefore one would not expect to find as many dune-pocketed drainage systems along the northern shoreline as south of Manistee. This last major advance of glacial ice began to retreat from the Lake Michigan basin approximately 14,000 years ago.

With the retreat of each glacial advance, meltwater filled the basin between the ice and the material the glacier had deposited. Each glacial period had pro-glacial Great Lakes whose shorelines, depths, and drainage outlets were very different from those of the present. The historical sequence of glaciation and the subsequent lakes has been interpreted and re-interpreted by various authors since the late 1800's. Until very recently these interpretations were based on a rigid earth crust concept which postulated a "hinge-line" effecting the pro-glacial lake sequence. A modification of the theory of crustal rebound published recently by Larsen (1987), based on the earth's crust responding as a visco-elastic crust to ice loading, invalidated the hinge-line notion and prompted a significant adjustment in chronology of the Lake Michigan Basin. Larsen's interpretation is adequate to explain salient aspects of drainage development. Accordingly, the following synopsis is provided from his recent paper:

> "...Separate proglacial lakes draining southward through the Chicago and Port Huron outlets occupied the Michigan and Huron basins, respectively. Lake Chicago stood at its Calumet level of 189 m (620') while Early Lake Algonquin filled the southern Huron basin, possibly at a 184.5 m (605') level [Figure 2a -- reproduction of Larsen's figure 15]. Ice retreat into a progressively deepening isostatic depression caused deglaciation of successively lower northern outlets, which in turn caused the lakes to fall..."

> "Deglaciation of the Lake Michigan basin was accompanied by northward expansion of Calumet-level Lake Chicago until drainage channels to the Huron basin were uncovered north of Traverse City, Mich. Drainage through the Indian River lowland possibly linked the two lake basins briefly, joining the Calumet level of Lake Chicago with the Main Algonquin of Huron [Figure 2B -- reproduction of Larsen's figure 16]."

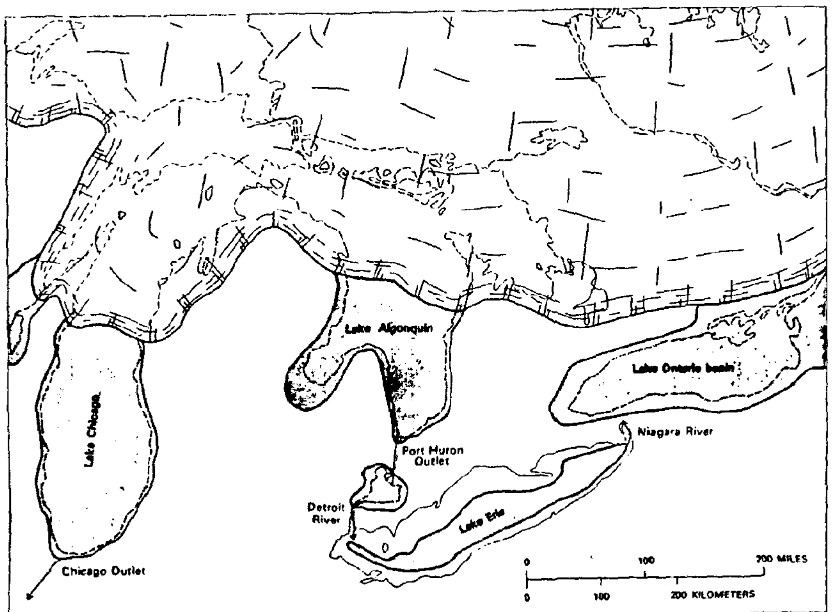


Figure 15. Calumet-level Lake Chicago and Early Lake Algonquin. Overflow was to the south at Chicago and Port Huron at the maximum advance of Two Rivers ice about 11,800 yr B.P. Early Lake Erie drained to the Lake Ontario basin.

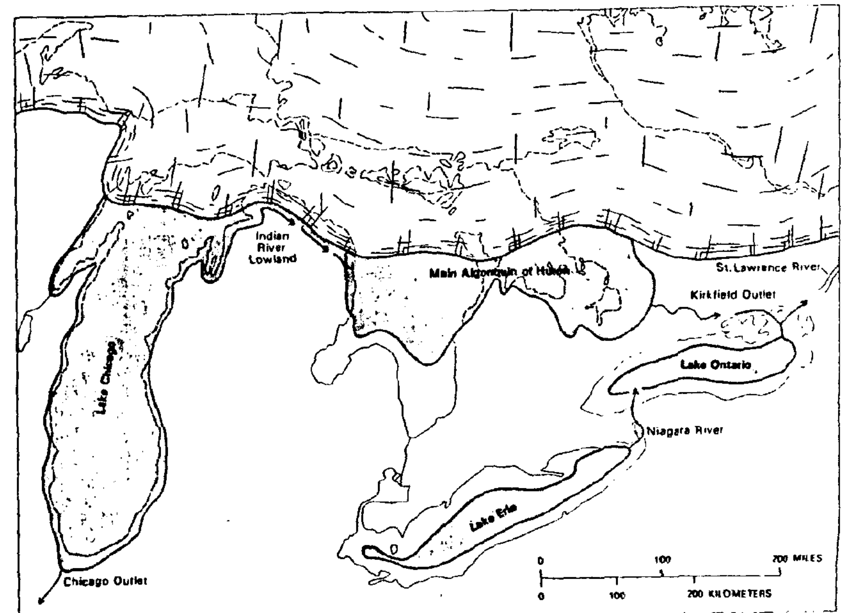


Figure 16. Calumet-level Lake Chicago and the Main Algonquin level of Lake Huron (MAH) (11,600 to 11,300 yr B.P.). Overflow was to the south at Chicago and eastward to Early Lake Ontario at Kirkfield. The Michigan and Huron basins were possibly linked by drainage through the Indian River lowland south of the Mackinac Straits. Lake Erie overflowed to the Lake Ontario basin.

Figure 2. Early pro-glacial lakes of the Lake Michigan basin.
A. Early Lake Chicago
B. Later Lake Chicago
Notice that Lake Algonquin did not occupy the Lake Michigan basin during this time according to the chronology presented by Larsen (this figure is reproduced from Larsen, 1987 -- figure numbers 15 and 16 are Larsen's numbers).

"Deglaciation of the Mackinac Straits at about 11,200 yr B.P. joined the basins at depth. The Main Algonquin of Michigan dates from this period and represents a single water plane draining to the north through the Fossmill system and probably controlled by the Mink Lake sill at 328 m. This isostatically depressed outlet channel caused the level of Lake Michigan to fall to a low of about 61 m (200') in the southern basin...[Figure 3A — reproduction of Larsen's figure 17]."

"The lakes underwent their final fall when ice receded from North Bay. The level of Georgian Bay dropped to as low as 62m....The Lake Michigan level, in turn, fell to a plateau near 160m at the Mackinac Straits and subsequently eroded the Mackinac River channel to a controlling threshold now at about 140m. This spillway governed a lowered level of the lake, creating a separate lake in the south at an altitude of about 55 m (180') that overflowed northward through a channel near Muskegon (Hough, 1958, p241). The slow rise from the early Chippewa low level in the southern basin was controlled by uplift of the Mackinac Straits..."

"The low-level phases of Lake Michigan...(Figure 4, bottom left, from Larsen's table 4) were progressively ended by uplift of the controlling spillway at North Bay....A transgression, led by the expanding lake in the Huron basin and caused by the steadily rising North Bay outlet, rejoined the Michigan and Huron basins at the Mackinac Straits after 8,150 yr B.P. The episode marked the end of separate low-level phases in the lakes and initiated the pre-Nipissing transgression."

"Once drainage to the south was established, the outlet configurations and probable paleoclimatic influences on water volume became major variables in the system. Lake level fluctuated about a mean altitude adjusted to the cross sections of the southern outlets. Before 4,500 yr B.P., the record of lake-level change is poorly known; however, distinct high levels occurred at 4,500, 4,000, and 3,200 yr B.P. (Larsen 1985a,b). These highs, referred to as the Nipissing I, Nipissing II, and Algoma levels are identified by terraces that rise exponentially with distance from the southern shores of Lake Michigan to the North Bay region (Larsen, 1985b). They reflect probable high-amplitude fluctuations related to runoff variations in the drainage basins. The permanent outlet channel linking North Bay with the Mattawa River maintained a level adjusted to its rising sill. Isostatic uplift finally raised the North Bay sill above the southern outlets between

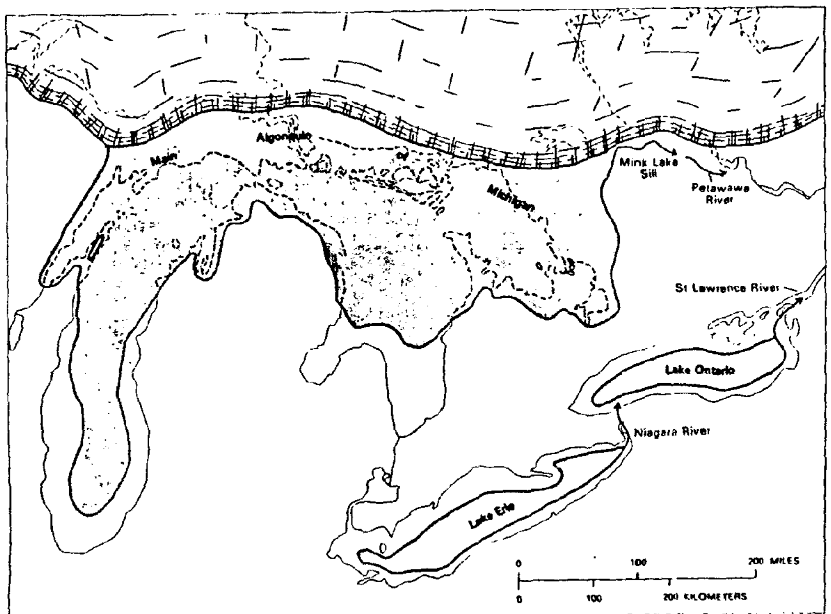


Figure 17. Main Algonquin level of Lake Michigan confluent with the Orillia (?) level of the Lake Huron basin (11,200 to 11,000 yr B.P.). Overflow was eastward to the Ottawa valley at the Mink Lake sill. Lake Erie and Lake Ontario basins contained low lakes controlled by rising northeastern outlets (fig. 5, case 3), which show rising water levels along their western shores.

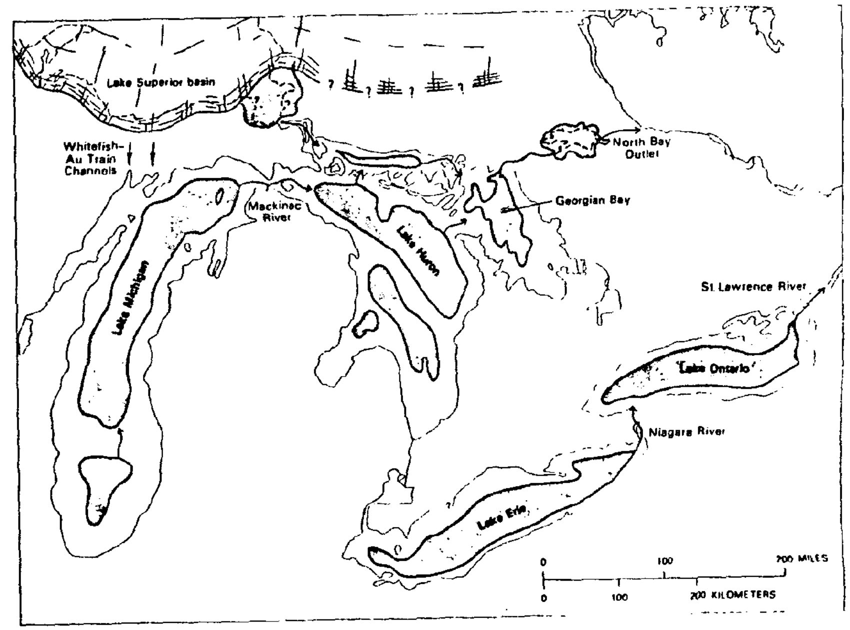


Figure 18. Chippewa and Stanley low levels. Marquette ice filled the Lake Superior basin and supplied overflow through the Whitefish-Au Train channels (9,900 yr B.P.). The upper Great Lakes drained eastward to the Ottawa valley across a controlling sill at North Bay that was deglaciated as early as 10,300 yr B.P. Chippewa-level Lake Michigan overflowed eastward through the Mackinac River channel. Separate lakes occupied the deep basins of Lake Huron and overflowed across the Niagaran escarpment into the Hough low level in Georgian Bay. Lake Erie and Lake Ontario continued to rise and expand westward as their outlets rose.

Figure 3. Main Algonquin of Michigan and Lake Chippewa pro-glacial lakes of the Lake Michigan basin.
A. Main Algonquin of Michigan (MAM)
B. Lake Chippewa
This figure is reproduced from Larsen, 1987 -- figure numbers 17 and 18 are Larsen's numbers.

> 4,500 and 4,000 yr B.P. The Chicago outlet was abandoned after 4,000 yr B.P., and the modern drainage system at Port Huron came into being. Since then, lake levels have continued to fluctuate adjusted to a single outlet channel."

The lowest stage, termed Lake Chippewa, has been recognized for several decades. It occurred just after the the North Bay outlet opened but before isostatic rebound had raised the level of the northern outlets. This extremely low lake stage (some 400' below present lake level) had profound effects upon drainage in the Lake Michigan basin. These effects will be described more fully in the next section on drainage processes.

Crustal rebound is an important factor in the development of shoreline landscapes. The uplift of each lake stages' shoreline features (beaches and dunes) becomes progressively (exponentially) more pronounced to the north. This effect dominates drainage patterns north of approximately Portage Lake in Benzie County, but the entire shoreline has been uplifted. Drainage patterns between approximately Ludington (Mason County) and Portage Lake (Benzie County) show some noticeable effects of isostatic rebound and this area may be considered a transitional zone between the minimally effected areas to the south and the greatly effected northern areas.

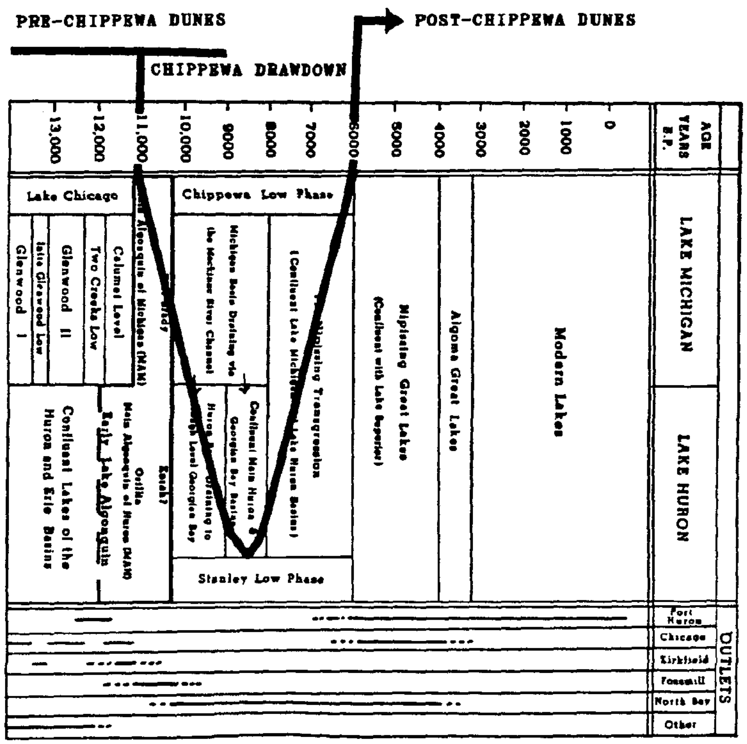
III.B Surface Drainage Processes

The erosive action of surface water runoff on the Michigan landscape has only been operating since the last glacier retreated from the land, about 14,000 years ago. That is a short time in terms of most geologic processes, and the Great Lakes drainage system is poorly developed, especially in comparison to older systems such as the Mississippi River. The ultimate result of surface water drainage over a very long time is a reduction of the upland to a featureless plain at base level. Base level for the Great Lakes drainage system is sea level, but for the landscapes in western lower Michigan, base level is 580', the present level of Lake Michigan.

The erosive energy of a surface drainage system is approximated by stream discharge (cross-sectional area per unit time). Very generally, a stream's discharge is determined by the size of its surface watershed and the gradient within the watershed. Watershed area approximates total water volume collected, and gradient approximates velocity due to gravity. Other factors such as loss of volume to groundwater and evapotranspiration are also important.

Drainage systems develop by a process called stream gradation. Generally, the erosive energy in the stream works to smooth out the gradient to base level, and as it does it erodes upgradient. This erosion may "capture" a nearby stream or lake, enlarging the watershed. Further enlargement and steepening of the gradient as the watershed grows increases erosive energy, continuing the cycle. Ultimately, the result of the expansion process would be only a few very large rivers draining to base level. Within the Lake Michigan basin, drainage systems are young and their development has been complicated by changes in base level.

As the glacier first uncovered the landscape, most well-defined stream watersheds were probably small, and the surface gradient was not much steeper than it is today. Early drainage into Lake Chicago was likely quite slow in development. However, the opening of the North Bay drainage outlet about 4,000 years later must have had a dramatic effect on stream gradation as base lake levels dropped nearly 400' to the Lake Chippewa stage. This effect was probably most pronounced along deeper nearshore areas where the position of the shoreline did not shift very far as lake levels dropped. Figure 4A, simplistically depicts the "Chippewa drawdown" in relation to Larsen's chronology, and shows the area occupied by Lake Chippewa at its minimum (Figure 4B -- from Hough, 1958). This period probably accounts for much of the present upland drainage development. As the gradient steepened, the larger streams cut deep gorges and their drainage systems rapidly extended inland, except where sand dunes blocked drainage. Many of the streams that had been small, low-energy nearshore creeks draining into Lake Chicago became significant drainage systems with deeply eroded channels. There were probably many rapids and



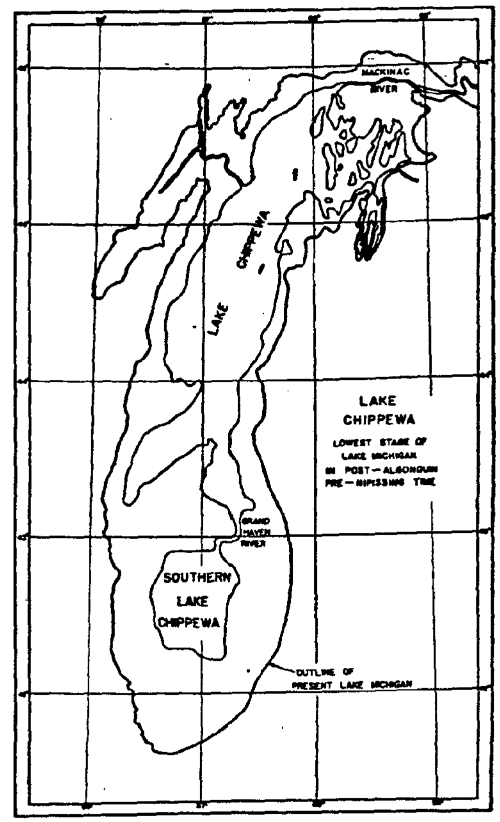


Figure 4. The "Chippewa Drawdown" (Figure 4A) from the Calumet level of Lake Chicago, through the Main Algonquin of Michigan, to a minimum level during Lake Chippewa, greatly affected drainage patterns along the Lake Michigan shoreline. From the viewpoint of their relationship to drainage development, dunes can be broadly distinguished as pre-Chippewa or post-Chippewa. Figure 4B shows the approximate shoreline location at minimum water level in Lake Chippewa (based on modern lake bottom contours), and the shoreline area exposed at that time (Map from Hough, 1958).

waterfalls during this period as streams flowed over unconsolidated glacial material and possibly bedrock in some areas.

Including the falling, low, and rising stages, the Chippewa drawdown probably lasted at least 5,000 years -- a relatively long duration among the post-glacial lakes. During this period of base-level lowering, upland drainage was accelerated, and deep river channels were cut. Many inland lakes and wetlands were probably drained by expanding stream watershed boundaries. Even after the base lake level began to rise, upgradient erosion probably continued at nearly the same rate for some time because of the gradient already established. When the base lake level reached 605' (Lake Nipissing), the deep river gorges were flooded well inland with lake water. Slowly they were filled with sediment eroded from the upland. Lake Nipissing levels were reached about 6,000 years ago and probably represented a slowdown in the development of upland drainage. Even though the total gradient of the Lake Michigan basin watershed was similar to that established earlier during Lake Chicago drainage, the pattern of drainage was different. Upland channels had been cut during the Chippewa drawdown. When Lake Nipissing dropped to the present level of 580', there was probably much less effect on the upland drainage patterns. The major rivers cut down through their bed deposits and are now meandering within the width of these alluvium filled channels.

III.C Shoreline Processes

While the erosive power of stream gradation constantly works to level the land, dune building and littoral drift have acted as depositional processes to move materials landward along the margins of the coast. Active forces that drive these processes include direct wind energy, wave action, and lake currents. All three of these forces simultaneously erode and deposit materials. The character of the resulting shoreline depends upon the balance between erosion and deposition.

The force of the direct winds that strike the eastern shoreline is undiminished as they blow across the expanse of Lake Michigan. In addition to their direct abrasive and erosive action, these winds carry sand inland from where it is exposed along the shoreline, depositing it as they lose energy. They also generate waves that both erode the shoreline and carry material shoreward. The steady force of the wind produces currents within the lake that move large amounts of material along the shoreline.

III.C.1 Dune Building -- The high sand dunes along the eastern and southern shores of Lake Michigan are not associated with the present stable lake level. A relatively constant lake level is not conducive to sand dune formation because sand that is piled on the beach is still within the reach of waves, either during periods of high water or during storms. The waves wash away the dunes before they can become large and stabilized.

Buckler (1979) emphasized that, "The environmental (climatic and geomorphic) conditions under which the dunes formed no longer exist; once destroyed, they are not likely ever to regain their present significant size and extent."

The important event that allows for the development of the high dunes is the lowering of lake level. When the lake level is lowered, waves cannot reach the forming dunes and erode them. Also, more sand is exposed to the wind when water level is dropped, providing the material for even higher dunes. Vegetation soon begins to grow on the dunes, stabilizing them from further wind erosion.

Most of the high dunes along the present shoreline were formed either formed during the drawdown of Lake Chicago (eventually to Lake Chippewa level), or as Lake Nipissing was being lowered to the present lake level. Ignoring minor variations in lake level that have produced a complicated series of beach terraces and subsequent corresponding dunes, we have labeled these major dune building periods as "pre-Chippewa" and "post-Chippewa."

Pre-Chippewa dune development during the Chippewa drawdown period may have been very extensive. However, because the level of Lake Chicago and Lake Nipissing was approximately the same, erosional washing by the rising waters of Lake Nipissing leveled any dunes below about 605'. What remains of pre-Chippewa dunes is probably only a small fraction of those originally formed. Large beds of lake bottom sand apparently occurred beneath Lake Nipissing. Some of the same sand that formed pre-Chippewa dunes during the drawdown to Lake Chippewa in locations presently offshore was probably redeposited later as part of the Nipissing and Algoma dunes. In most cases, the post-Chippewa dunes formed over top of, or at least adjacent to the remaining, most landward (oldest) pre-Chippewa dunes. These two sets of dunes essentially merged together into one large, dense dune barrier. However, due to the greater uplift of the land to the north, the pre-Chippewa dunes have been raised more, and the post-Chippewa dunes have formed on the old lake bottom somewhat lakeward and below the pre-Chippewa dunes.

Generally, the southern dune systems are more compact sand barriers, whereas the northern systems are more spread out both vertically and horizontally, and therefore less effective as barriers to drainage.

The Sleeping Bear Dunes of Leelanau County are a good example of a northern dune. Although the Great Sleeping Bear Dunes form an impressive feature that rises high above the shoreline, uplift of the underlying glacial deposits is responsible for much of the topographic relief. High dunes formed on glacial deposits are called perched dunes.

III.C.2 Littoral Drift -- Another important shoreline process of the Great Lakes is that of longshore currents and beach drift. During periods of beach erosion (storms or high water), sand is moved laterally along the beach by wave action or wind. When it reaches an area of decreased wave energy, such as a bay mouth or protruding shore feature, the lateral movement is decreased and sand deposition begins. This process can accumulate large amounts of sand in some areas, forming hooked spits, bays, or even closing off a lake. During the present period of rather stable lake levels and general wave erosion, longshore currents account for the majority of sand deposition. There are two forms of littoral drift: beach drift and longshore drift. Beach drift is caused by waves striking the beach at an oblique angle, lifting sand off the beach and depositing it a few feet up the beach. Longshore drift is a more dynamic process of currents that follow the shoreline. The prevailing winds cause the waters of Lake Michigan to flow in counterclockwise currents. Thus, along the eastern shore the water current is from south to north. These currents are generally quite strong, and they carry large amounts of sand with them. However, in areas where the current is weakened, such as behind a jutting point or across the mouth of a bay, the sand tends to be deposited. Reverse eddy currents are set up in areas behind these deposits which eventually establish opposing north to south deposits.

III.D Vegetational Processes

III.D.1 Species Migration and Colonization -- Within the frame of reference of geologic time, an important process effecting vegetation is species migration. The glaciers destroyed all vegetation in the area covered by the ice. The once circumboreal arctotertiary geoflora had earlier been divided into continental components (North American, European, Asiatic), but glaciation further segmented it into subcontinental isolates (Eastern North American, Western North American). Many of the species populations in these areas are similar but have undergone a degree of genetic evolution and now occur as species or subspecies pairs [e.g. eastern white pine (Pinus strobus) and western white pine (Pinus monticola)]. During the peak of the glacial epoch, plant populations survived in "refugia" south of the ice, particularly the Appalachian mountains. Some boreal species persisted along the ice front (as evidenced, for example, in the buried "Two Creeks" forest bed and in preserved trees beneath Lake Michigan). Between advances of the glacier these populations evidently migrated northward repeatedly, colonizing the exposed landscape. Migration establishes the geographical range of species and thus regulates the populations available to form a plant community.

Species that are available within the dune associated wetlands zone in northern Michigan are mostly similar to those found in wetland communities throughout the lower peninsula. Many species (e.g. Sassafras albidum, Nyssa sylvatica) extend further northward along the Lake Michigan shoreline than they do further inland within the state at the same latitude. This has been presumed to be due to the ameliorating effect of Lake Michigan on climate within the shoreline zone, and that no doubt is an important factor. However, patterns of colonization and migration are also important. These are related directly to prehistoric habitats that were available as source areas for species populations.

It is noteworthy that during the Lake Chippewa low water period extensive wetland and dune areas probably occurred in the area presently covered by Lake Michigan. These exposed lands may have been important in the development of the flora of the dunes and eastern Lake Michigan shoreline areas. During this stage, water levels dropped by approximately 400'. One need only to consider the extensive areas laid bare (see Figure 4B) in comparison to recent dune building on exposed areas, to gain some appeciation for vegetation colonization that might have existed during this time. For example, the Great Sleeping Bear Dunes area has been uplifted approximately 40 feet, equivalent to a drop in water level only about one-tenth as great as that experienced during the Chippewa drawdown. Yet extensive dune building has occurred. Large areas of beach, dune, and shoreline habitat have developed. Approximately three million acres of this type of habitat was probably opened during the Chippewa period. Many of the species presently found in the shoreline zone probably colonized this vast area, persisting along the narrowing shoreline as the lake rose, and then re-expanding their range as the lake fell from Nipissing level (605') to its present level (580').

III.D.2 Succession -- Another process affecting vegetation composition in the dune associated wetlands is plant succession. Succession was first described in relation to dune communities. On the dunes a complete series of vegetation communities is laid out spatially from the earliest colonizing species and species combinations along the shoreline and the foredunes, to stable climax forests farther inland. Succession has also effected the dune associated wetlands from their beginning until the present time. Much of the information that has developed during the past several decades regarding hydrosere succession has recently been summarized by Reuter (1986). The model developed by Reuter depicts a successional sequence similar to that occurring in many of the dune associated wetland areas along the Lake Michigan shoreline, particularly minerotrophic sites with a relatively high, stable watertable. We have employed this model as the basis for a successional development scale (Figure 5, upper portion). This scale ranges from 0, representing emergent aquatic vegetation, to 10, representing lowland forest. We term values on this scale "wetland succession values".

As depicted in Figure 5, at each stage along the successional spectrum disturbance factors also come into play. The effect of catastrophic disturbance on wetland succession has been well documented by a number of authors. Flooding and fire are the two

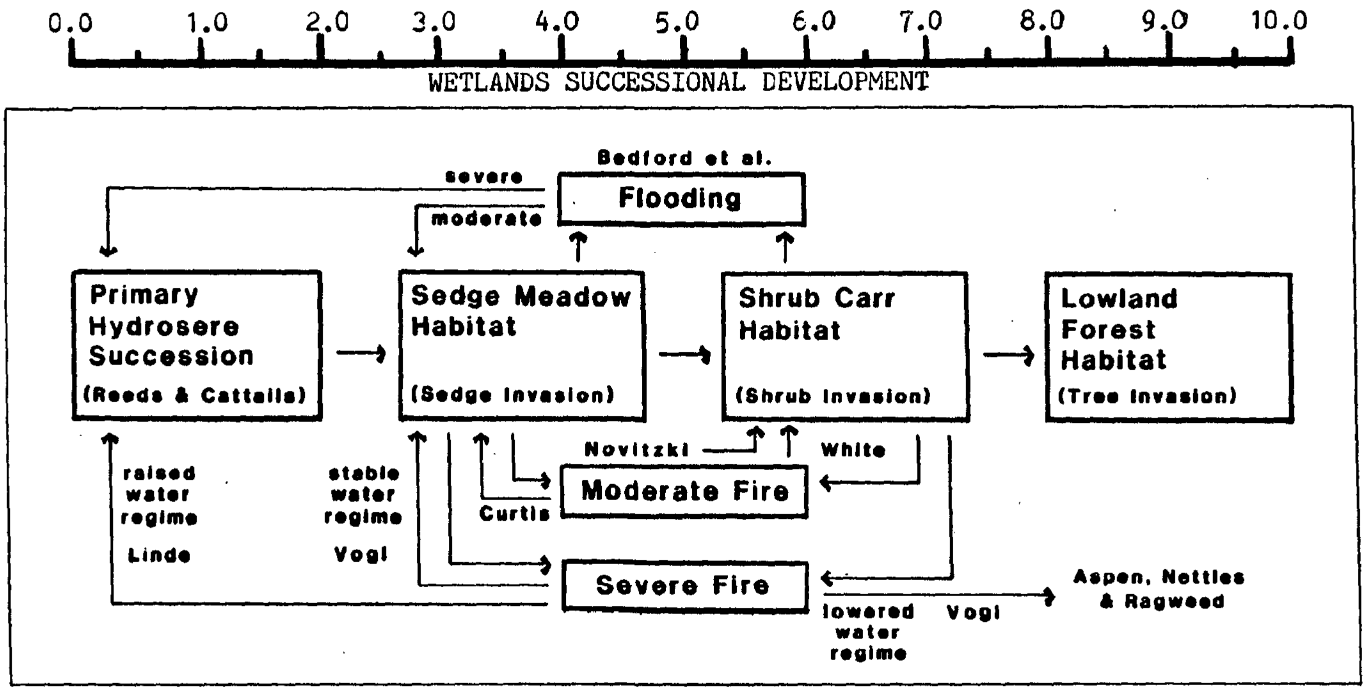


Figure 5. Wetlands succession model (lower portion) from Reuter (1986). This model shows typical plant community succession and disturbance of high water table, mineral rich areas. Authors names associated with reports of disturbance phenomena are indicated on the lower arrows. Wetland succession value (WSV) scale is shown in the upper portion of the figure.

natural factors having the greatest impact in retarding the successional process or setting a community back to an earlier stage of succession. Encroaching sand is also important in some areas close to the dunes. There is evidence that both flooding (e.g. by beaver works) and fire (Indian burning) were much more widespread and significant in presettlement time. Plant community composition represents an equilibrium between succession and catastrophic disturbance.

III.D.3 Mineral Enrichment -- Yet another factor affecting succession and the character of the vegetational community, is the degree of mineral enrichment (minerotrophy or ombrotrophy). Apparently most wetland communities in northern Michigan, including the dune-associated wetlands, began as minerotrophic communities. Wetlands usually occupy topographically lower positions on the landscape and therefore receive enrichment from the surrounding upland areas, either by surface runoff or through groundwater movement. For wetlands connected to groundwater the mineral regime of the wetland is related to the natural fertility of the surrounding landscape. Depending on the mineral characteristics of the surrounding watershed and the position of the wetland basin within the watershed, many wetlands, especially in sandy, naturally infertile areas located near the head of their watershed where little groundwater is possible, become increasingly acidic and lacking in the nutrients needed for organic matter decomposition. Eventually, they accumulate organic matter and develop a seal, process, we assigned a mineral enrichment value (0-10) to each of the sites examined (See Methods Section). Application of the succession model presented earlier (Figure 5) must take into account the mineral characteristics of the site. Mineral enrichment might be considered as an additional dimension of this model.

III.D.4 Seasonal Fluctuation of Water Level -- The most important single factor affecting many of the dune-pocketed wetlands catchment areas appears to be fluctuations in water level between early spring and late summer. Seasonally fluctuating water levels may be considered as a form of catastrophic disturbance. In this sense they could be thought of as a retrogressional factor in the model presented above. However, whether an environmental effect is considered a disturbance or simply as a component of the normal environment depends upon its frequency and predictability. In the catchments of landward dune-pocketed wetlands periodic flooding and drying is apparently the rule rather than the exception. Many of these wetland areas undergo extreme variation in water levels between spring and late summer. Because of their relatively large watershed area and comparatively small catchment area, it is not uncommon for catchment basins to be flooded to a depth of three to four feet in early spring. This kills most trees and other woody vegetation except those few species that are able to tolerate flooding. In some basins a small open water catchment pond or lake may persist throughout the summer due to connection to the ground water. Otherwise, the isolating them from groundwater. This process, termed ombrotrophication, is a positive feedback process. The developing organic seal further isolates the wetland from mineral input from groundwater which further reduces the rate of organic decomposition, increasing peat accumulation, etc. In contrast to the classic concept of bog vegetation formation by a floating mat in an open bog lake, most of the peatland areas associated with the shoreline zone have developed by paludification -- the outward growth of peat resulting from ombrotrophic conditions within the wetland. For this reason we prefer the term "peatland" to the term "bog" to characterize these communities.

Once wetland communities begin to shift over from marsh to peatland vegetation they seldom revert to marshes. Rare instances can be found of reversal of ombrotrophication where highways have been built, agricultural fertilization of the surrounding landscape has occurred, or where fire has resulted in a sudden and massive influx of cations into the wetland, but it appears to be a one-way process under most circumstances. Species typical of minerotrophic, marsh-like wetlands include cattail (Typha latifolia), Scirpus atrovirens, etc., many willows (Salix spp., etc.), whereas those more typical of ombrotrophic conditions include Carex oligosperma, Scirpus cyperinus, leatherleaf (Chamaedaphne calyculata), chokeberry (Nemopanthus murconata), etc. With some practice it is possible to estimate the degree of ground water influence (minerotrophication) of a wetland community by examining the species composition of the vegetation community. Using this water level in these flooded areas gradually drops as the season progresses and by late summer these sandy areas may become very dry. The extreme drying experienced by the plant community further limits the complement of species persisting on the site.

We devised and applied a water constancy index to each site (see Methods Section), but found that it was meaningful only in the catchment areas. Even there scaling of water fluctuation is complicated by zonation of the vegetation due to overall water level as well as the extent of variation. The most extremely fluctuating portions of the landward dune-pocketed wetlands catchment areas remain denuded of vegetation throughout the year. Surrounding these there is usually a zone dominated by amphibious perennial plants (e.g. Polygonum amphibium, Proserpinaca palustris) and weedy annuals (e.g. Conyza canadensis). Continuing outward toward the margins of the catchment basin one typically finds a sedge meadow zone, surrounded by shrubs (particularly Salix petiolaris). Sedge meadow, shrub carr, and open lowland forest form extensive wetland areas upgradient from the wetland catchments in some of the dune-pocketed wetlands watersheds.

IV. CLASSIFICATION OF EASTERN LAKE MICHIGAN DRAINAGE SYSTEMS

The formation of post-glacial sand dunes of both pre-Chippewa and post-Chippewa age had a pronounced effect on the development of drainage throughout the eastern part of the Lake Michigan watershed. The glacial process established the framework for drainage patterns and also altered those patterns by fluctuation of base lake levels and rebound of the earth's crust. Dunes impeded drainage in many areas. The interaction of these processes formed the present shoreline of eastern Lake Michigan. This section will describe and classify the shoreline drainage systems in terms of their process of formation.

The purpose of this classification scheme is to place dune-pocketed wetlands in proper order with previously recognized shoreline drainage systems. We have defined the dune-pocketed wetlands drainage system type as an ancient stream watershed that previously drained to Lake Michigan but has since been blocked by the formation of sand dunes. Therefore, the drainage system classification is generally based on the degree of sand dune impedance of all Lake Michigan drainage areas.

The Lake Michigan watershed is subdivided into a set of stream watersheds. Each stream that enters at the Lake Michigan shoreline is considered a first-order stream and it drains an entire upgradient watershed. Within that watershed, there may be subordinate streams that drain into the first-order stream. Also, there may be areas that do not drain by surface flow to any stream in the watershed, such as glacial kettle lakes. If areas are within a first-order watershed divide they are considered part of the first-order stream watershed, and generally drain to that stream through groundwater flow. Figure 6 is a map that shows the larger first-order stream watersheds within Michigan's lower peninsula.

In classifying the shoreline, the area north of Manistee has shoreline drainage patterns that are much less well-defined than the southern region. The northern area was affected greatly by the last glaciation, as well as by uplift of the land. In the cross-hatched area in Figure 6, north of Frankfort (Crystal Lake) the drainage systems are so poorly defined, and the effect of dunes on drainage is so slight, that we did not attempt to map all of the watershed divides in that area. Repeated examinations found no dune-pocketed wetlands in the northern region, with one possible exception. The Billiau Hill area in Wilderness State Park, Emmet County (Bliss Quadrangle) was originally suspected as a possible dune-pocketed wetland, and has some similar characteristics, but the process of formation (considering uplift of the land) is decidedly different from the southern set, and it is not included in our analysis. The boundaries of all drainage systems (watersheds and drainage areas) along the shoreline from the Indiana border to the Betsie River (Benzie County) were mapped. All are classified and cited in Appendix II. Listings of all dune-related types are given below.

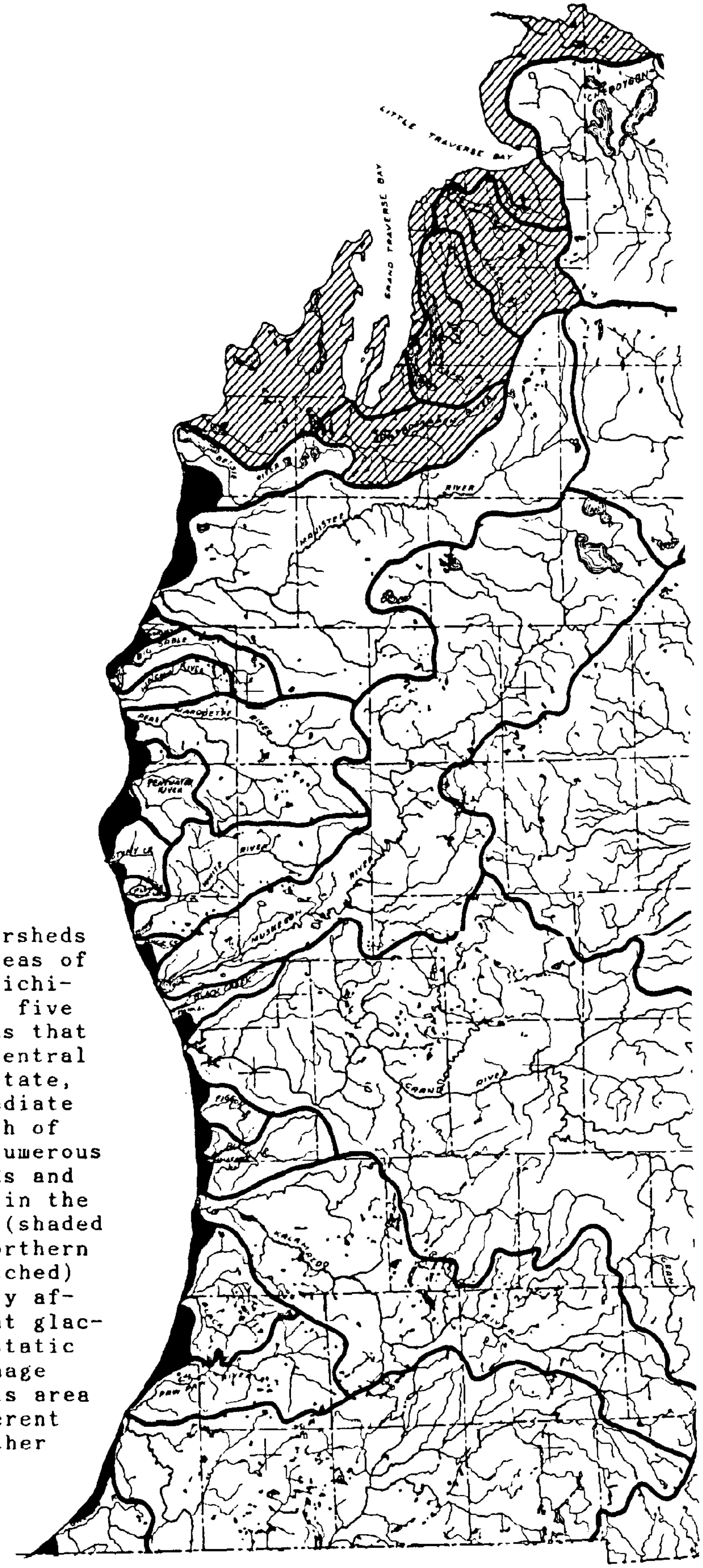


Figure 6. Watersheds and drainage areas of western lower Michigan. There are five major watersheds that extend to the central divide of the state, fifteen intermediate watersheds south of Manistee, and numerous small watersheds and drainage areas in the shoreline zone (shaded black). The northern area (cross-hatched) has been greatly affected by recent glaciation and isostatic rebound. Drainage patterns in this area are quite different from those farther south.

The area shaded black in Figure 6 is the shoreline drain zone. Within this zone, there are numerous small first-order streams. Some of the creeks only flow a few hundred yards inland and may be intermittent, but they have developed definite stream channels. There are also shoreline drainage areas that do not drain to a first-order stream. These are shoreline drainage types where surface water enters Lake Michigan either by overland sheet flow or by groundwater seepage. Generally, direct surface sheet flow occurs only nearshore, and depends on soil type, gradient, and amount of water. All other surface water falling within the shoreline drain zone that does not drain to a stream is isolated from Lake Michigan. Ultimately, this water will evaporate or flow to Lake Michigan as groundwater.

The shoreline drain zone generally consists of sand dune systems and glacial landscapes. Within the set of isolated surface water drainage areas, each water or wetland feature is classified as either dune-formed or glacially-formed. The basis for distinction is that glacial catchments have been isolated since the retreat of the last glacier. The dune-formed areas have only been isolated since development of the dunes (mostly Main Algonquin of Michigan, Nipissing, Algoma, or Recent), and were probably draining to the lake basin prior to that.

Non-dunal isolated surface drainage may occur because of glacially formed depressions, a very gentle gradient, or an undulating glacial terrain (moraines and till fields). These areas do not have adequate surface water erosive energy to form channels and drain the land. Glacial lakes and wetlands may occur proximate to sand dunes, and in some cases may not be immediately discernable from those that are dune-formed. Generally, if there is a ridge of non-dune material between the lake or wetland and Lake Michigan, it is a glacial lake. In cases where that distinction is difficult to determine from topographic maps, the landward watershed boundary can usually still be delineated. If the watershed is small relative to the size of the lake, it can generally be assumed to be of glacial origin. Many glacial lakes were formed from large pieces of ice that were left buried in the till as the glacier receded, or in basins gouged out by the erosion of a glacier.

Within the set of dune-formed drainage areas, we recognize three general wetland formation types. Because of the highly permeable soils, much of the surface water that falls on dunes is absorbed and flows to Lake Michigan as groundwater. The dune-formed surface water catchment types are described briefly in the following paragraphs.

IV.A Interdunal Wetlands

The interdunal wetland has been recognized by the Michigan Natural Features Inventory (MNFI) as a distinct community type. MNFI describes these wetlands as "typically found in long troughs between dune ridges, in wind-excavated depressions at the base of blowouts, in hollows of dune fields wedged between inland lakes and the Great Lakes, and in old river channels that once flowed parallel to the lakeshore behind a foredune". Many interdunal wetlands have fluctuating watertables seasonally and yearly, related to changes in base lake level. In some instances they may be ephemeral features. They occur as ponded areas only because of the basins formed by sand dunes, and most of these areas probably drained by sheet flow prior to dune formation.

In conducting our inventory, we initially identified several areas as small dune-pocketed wetlands which we are now calling transitional interdunal wetlands. These are wetlands that occur at the landward base of the dunes, but have very small drainage areas and essentially no evidence of drainage development. It was not within the scope of this study to inventory interdunal wetlands, as MNFI is responsible for that task.

IV.B Bay Mouth Bar Lakes

These lakes were originally bays of Lake Michigan, formed either by glacial carving or sand deposition of hooked spits. Where these bays occurred, wave energy was decreased at their mouth, allowing for the deposition of sand bars by littoral drift. As these bay mouth sand bars accumulated more sand, they began to effectively close off the mouth of the bay from Lake Michigan, forming a nearshore bay mouth bar lake. Generally, the sand bars that began to close the bay were overridden by the formation of sand dunes. In some cases, the level of the bay mouth bar lake has remained at the 605' elevation it was formed at, or even been uplifted higher. In others, when lake level dropped to 580', the bay mouth bar lake also dropped to that level.

All first order streams that flowed into the original bay are now re-ordered. If the lake has maintained a stream outlet, the original streams become second order. If the bay mouth bar lake is entirely closed off from Lake Michigan, the streams draining into the new lake are essentially isolated from Lake Michigan in terms of surface drainage. In either case, the original streams will continue to develop as if they were first order streams, unless affected by uplift. The formation process of this dune-associated wetland type was further described by Scott and Dow (1932) in a descriptive case study of the Herring Lakes in Benzie County.

A list of all bay mouth bar lakes formed along the eastern shoreline of Lake Michigan is given in Table 2.

IV.C Dune-Pocketed Wetlands

The dune-pocketed wetland type developed as a first order stream, but has since been blocked by sand dunes. Many of these naturally dammed streams have since been artificially drained. These areas normally have some dendritic drainage in the upland, and collect into a catchment right at the base of the dunes. The watershed boundary for the dune-pocketed wetland nearly always defines the landward limit of the shoreline drain zone. The possible formation processes of this type will be further described in the following section. Table 3 lists the Dune-Pocketed Wetland Watersheds of the eastern Lake Michigan shoreline.

Although the dune-pocketed wetland is the only first order stream now blocked by sand dunes, it can be assumed that many of the streams that presently drain may have been impeded by dune development. The factors that determine a stream's degree of impedance are its erosive energy (discharge), and the size of the dune barrier. During the two major dune-building periods, base lake level was dropping, so stream energy was increasing. Below is the classification of the first-order streams south of Frankfort in terms of their degree of dune-impedance.

Table 2. Bay mouth bar lakes along the eastern shoreline of Lake Michigan (listed south to north).

Number	Name	County	Quadrangle Sheet
LM025	Grand Mere Lakes Drainage Area	BERRIEN	BRIDGEMAN/STEVENSVILLE
LM118	Silver Creek (Lake) Watershed	OCEANA	LITTLE SABLE POINT/MEARS
LM122	Bass Lake Watershed	OCEANA+	PENTWATER
LM136	Big Sable (Hamlin Lake) Watershed	MASON	HAMLIN LAKE
LM154A	Bar Lake Watershed	MANISTEE	PARKDALE
LM154B	South Bar Lake Swamp Watershed	MANISTEE	PARKDALE
LM154C	North Bar Lake Outlet Watershed	MANISTEE	PARKDALE
LM158	Portage Lake Watershed	MANISTEE	PARKDALE
LM801	Arcadia Lake	MANISTEE	ONEKEMA
LM802	Upper and Lower Herring Lake	BENZIE	ELBERTA
LM804	Crystal Lake	BENZIE	FRANKFURT/BEULAH
LM807	North and South Bar Lakes	LEELANAU	EMPIRE

Table A2-2. Dune-pocketed wetlands watersheds of the eastern Lake Michigan shoreline (listed south to north).

Number	Name/Code	County	Quadrangle Sheet
LM019	Warren Dune-Pocketed Wetlands Watershed (WD)	BERRIEN	BRIDGEMAN
LM022	Thornton Valley Dune-Pocketed Wetlands Watershed #1 (TV1)	BERRIEN	BRIDGEMAN
LM023	Thornton Valley Dune-Pocketed Wetlands Watershed #2 (TV2)	BERRIEN	BRIDGEMAN
LM039	Mud Lake Dune-Pocketed Wetlands Watershed (ML)	BERRIEN+	COLOMA/COVERT
LM040	Fish Cemetery Dune-Pocketed Wetlands Watershed (FC)	VAN BUREN	COVERT
LM043	Dyckman Swamp Pocketed Wetlands Watershed (DS)	VAN BUREN	COVERT
LM074	Saugatuck Dune-Pocketed Wetlands Watershed (SD)	ALLEGAN	SAUGATUCK
LM076	Gilligan Lake Dune-Pocketed Wetlands Watershed (GL)	ALLEGAN	SAUGATUCK
LM078B	Kelly Lake Dune-Pocketed Wetlands Watershed (KL)	OTTAWA	HOLLAND WEST+
LM095	Muskrat Lake Dune-Pocketed Wetlands Watershed (MS)	MUSKEGON	DALTON/MICHILINDA
LM103	Fruitvale South Dune-Pocketed Wetlands Watershed (FS)	MUSKEGON	FLOWER CREEK
LM104	Fruitvale North Dune-Pocketed Wetlands Watershed (FN)	MUSKEGON	FLOWER CREEK
LM113	Long Lake Dune-Pocketed Wetlands Watershed (LL)	OCEANA	TOWN CORNERS
LM114	Skinny Lake Dune-Pocketed Wetlands Watershed (SL)	OCEANA	TOWN CORNERS
LM117	Bigsbie Lake Dune-Pocketed Wetlands Watershed (BL)	OCEANA	BIGSBEE LAKE+
LM138	Nordhouse Lake Dune-Pocketed Wetlands Watershed (NL)	MASON	HAMLIN LAKE
LM139	Spartina Marsh Dune-Pocketed Wetlands Watershed (SM)	MASON	HAMLIN LAKE
LM146	County Line Road Dune-Pocketed Wetlands Watershed (CL)	MASON+	MANISTEE

IV.D Somewhat Impeded Shoreline Streams

These streams occur within the shoreline drain zone and do drain to Lake Michigan but their flow is somewhat impeded (Table 4). Most of these streams appear to have developed as dune-pocketed wetlands, and still have a dune-base catchment, but have since developed drainage. Some of them (Sloan Pond, Pierson Drain) run along the base of the dunes until they empty into a first order stream. Others (Little Flower Creek, Section 33 Creek) drain behind the dunes until they reach a low spot and then drain directly to the lake. Two of them (New Buffalo Lake Watershed, Little Pigeon Creek) appear to have developed as drowned river mouth lakes, but do not extend inland beyond the shoreline drain zone.

IV.E Intermittent Stream Channel

This class of first order streams may also be considered as a type of somewhat impeded shoreline stream (See Table 4, lower part). Most its members occur in very sandy soils and are limited by the amount of water that they drain. The only area south of Frankfort in which such streams occur is in the vicinity of the Fruitvale Dunes. In that area there are several relatively well developed intermittent stream channels. These may have carried more water during ancient times or their channels may simply

Table 4. Upper Portion -- Somewhat impeded streams of the eastern Lake Michigan shoreline (listed from south to north). Lower portion -- intermittent stream channels of the eastern Lake Michigan shoreline zone.

Number	Name	County	Quadrangle Sheet
LM004	New Buffalo Lake Watershed	BERRIEN	NEW BUFFALO WEST
LM041	Brandywine Creek Watershed	VAN BUREN	COVERT
LM075	Halfway Creek Watershed	ALLEGAN+	SAUGATUCK+
LM080B	Ten Hagen Creek (Sloan Pond) W.	OTTAWA	HOLLAND WEST+
LM083	Little Pigeon Creek Watershed	OTTAWA	PORT SHELDON
LM098B	Pierson Drain Watershed	MUSKEGON	FLOWER CREEK
LM105	Little Flower Creek Watershed	MUSKEGON	FLOWER CREEK
LM147	Section 33 Creek Watershed	MANISTEE	MANISTEE
LM100	Lehman Road Intermitent Dendritic Drainage Area	MUSKEGON	FLOWER CREEK

reflect a highly erodible and yet very porous substrate. They lie in a sandy area between the heavy tills of the "Claybanks" area and the shoreline. In this area there is a complete gradation from deeply cut channels presently occupied by lakes (drowned river mouths), through dune-pocketed wetlands apparently not having sufficient energy to cut through and limit dune development, to these intermittent stream channels which do not have enough water even to make it to the lake. North of Frankfort, intermittent streams are very common flowing off the high glacial bluffs and then being absorbed into the wide, sandy beach that has been uplifted.

IV.F Unimpeded Shoreline Streams

These are first-order shoreline drain zone watersheds with no apparent impedance to stream flow from dunes. These streams drain through both dune and non-dune areas. Many may have been blocked by ancient pre-Chippewa dunes which formed during the Chippewa drawdown. When Lake Nipissing rose back to the original Algonquin level, waves would have eroded much of the pre-Chippewa dunes, allowing some blocked streams to begin draining again. Careful study of the drainage patterns of each of these streams suggests which were dune-pocketed in ancient times and which were not, but such analysis is beyond the scope of this report.

IV.G Drowned River Mouth Lakes

These are lakes that are generally associated with the larger inland-draining rivers in the eastern Lake Michigan basin. They are related to dunes. Spits of bars formed across the mouths of these rivers to partially block their flow to the lake. Dunes have enhanced the process. Table 5 lists all drowned river mouth drainage systems of the eastern Lake Michigan shoreline. Evans (1937) early characterized this partially unformed drainage type well:

> "Closely connected in their origin with the history of the terraces and dunes is a series of lakes along the shore from Saugatuck to Frankfort. They are of all sizes up to four or five square miles in area and separated from Lake Michigan only by the sand dunes. Their surfaces are generally only few inches above that of the big lake, and the natural drainage is through shifting, sand-choked channels....In many places the natural outlets were straightened and channels were cut (by man) that are easily maintained at depths sufficient for navigation; in this way perfect landlocked harbors were formed....
>
> The physiographic history of these harbor lakes is interesting and unique and is, of course, intimately linked with that of the

Table 5. Drowned river mouths of the eastern Lake Michigan shoreline (listed from south to north).

Number	Name	County	Quadrangle Sheet
LM005	Galien River Watershed	BERRIEN	NEW BUFFALO EAST
LM028	St. Joseph River Watershed	BERRIEN	BENTON HARBOR+
LM072	Kalamazoo River Watershed	ALLEGAN	SAUGATUCK+
LM078A	Lake Macatawa Watershed	ALLEGAN	SAUGATUCK+
LM080A	Pigeon River Watershed	OTTAWA	PORT SHELDON+
LM085	Grand River Watershed	OTTAWA	GRAND HAVEN
LM089	Mona Lake (Black Creek) Watershed	MUSKEGON	MUSKEGON WEST
LM091	Muskegon River Watershed	MUSKEGON	MUSKEGON WEST+
LM096	Duck Lake Watershed	MUSKEGON	DALTON/MICHILINDA
LM098	White Lake Watershed	MUSKEGON	MICHILINDA+
LM107	Flower Creek Watershed	MUSKEGON	FLOWER CREEK
LM115	Stony Lake Watershed	OCEANA	TOWN CORNERS+
LM120	Pentwater Lake Watershed	OCEANA	PENTWATER
LM132	Pere Marquette River Watershed	MASON	LUDINGTON
LM134	Lincoln River Watershed	MASON	LUDINGTON
LM152	Manistee River Watershed	MANISTEE	MANISTEE/PARKDALE
LM803	Betsie River	BENZIE	ELBERTA/FRANKFURT

> diversified history of the Great Lakes themselves....
>
> The development of the coastal lakes after the retreat of the ice may be treated as follows: As the waters of Lake Chicago and Lake Algonquin fell, the streams cut down. When the waters rose again during Nipissing time, the streams were ponded up at the mouth and did some sidecutting. This ponding was aided somewhat by the deposition of dune sand. The fall of the Lake Nipissing level caused the streams again to cut down rapidly; but near the mouth they continued clogged with sand, so that sidecutting also continued...."

During the Chippewa drawdown, base level for these rivers dropped by approximately 400'. It is apparent from the size of their watersheds and the width and depth of their channels that they were not impeded by the pre-Chippewa dunes. The sidecutting that occurred as the river meandered within its alluvium-filled channel produced the equivalent of a bay, and allowed sand to accumulate across its mouth by longshore drift. When Nipissing levels fell, dunes may have formed on those sand bars. However, because of the large amount of energy associated with the large watersheds, it is doubtful that these sand barriers could ever completely separate the lakes occurring at their mouths from Lake Michigan.

IV.H Unimpeded Inland Streams

These inland streams are not sufficiently ponded at their mouth to be considered drowned river mouth lakes. Generally their watersheds are not as large as the drowned river mouth lakes, and they occur in areas where the gradient to Lake Chippewa was not as steep. These streams are essentially the opposite of the dune-pocketed wetland type -- not at all dune-impeded, and draining well inland. Some of these streams may have been somewhat dune-impeded during the Chippewa drawdown by dunes that have since been removed by erosion. However, for present purposes, these streams are considered non-dune-associated.

V. DESCRIPTION OF DUNE-POCKETED WETLANDS WATERSHEDS

Application of the classification and screening criteria to all drainage systems of the Lake Michigan shoreline resulted in recognition of eighteen dune-pocketed wetlands watersheds. They are listed in Table 3 above. These watersheds have blocked drainage that suggests they would have been normal direct drain stream watersheds had they not been blocked by the dunes. They are characterized by wetlands that lie at the base of sand dunes. They differ from one another in several ways. The following paragraphs provide descriptions and data summaries for each of the dune systems having dune-pocketed wetlands watersheds (topographic maps of each site are included in Appendix II). Figure 7 shows the location of each. Vegetational characteristics of several of these (as well as other case study examples) are described in Appendix I.

V.A Warren Dunes System

The general character of the inland in this system is old lake bottom, and rather flat. There is extensive agricultural development here. The Warren Dunes are substantial barriers. This system dates back to the earliest dune forming period (Glenwood). The weakly developed drainage channels provide evidence of pre-Chippewa dune pocketing. The South Branch of Painterville Drain has well developed, deeply cut drainage channels,

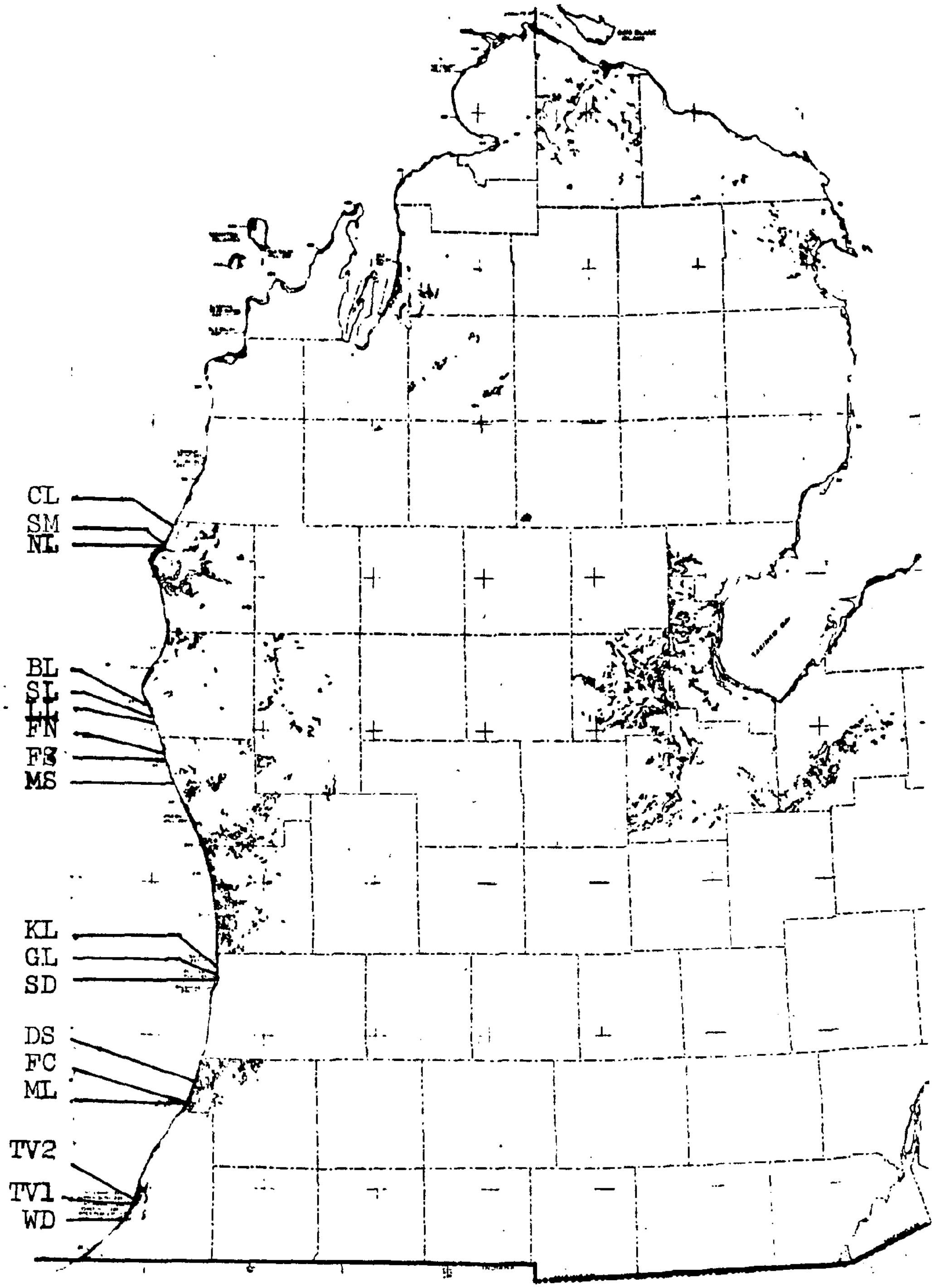


Figure 7. Location of dune-pocketed wetlands watersheds along the eastern Lake Michigan shoreline. Names corresponding to these codes are: WD-Warren Dunes, TV1-Thornton Valley #1, TV2- Thornton Valley #2, ML-Mud Lake, FC-Fish Cemetery, DS-Dyckman Swamp, SD-Saugutuck Dunes, GL-Gilligan Lake, KL-Kelley Lake, MS-Muskrat Lake, FS-Fruitvale South, FN-Fruitvale North, LL-Long Lake, SL-Skinny Lake, BL-Bigsbie Lake, NL-Nordhouse Lake, SM-Spartina Marsh, CL-County Line Road.

Chippewa). The North Branch of Painterville Drain is much less deeply incised, indicating recent artificial drainage. Drainage development is apparently pre-Chippewa behind the entire dune system north to Grand Mere Lakes. However, artificial agricultural drainage and the construction of I-94, Red Arrow Highway, and the town of Bridgeman, have altered original drainage patterns considerably. Most of the wetlands have been drained.

We recognized three dune-pocketed wetlands watersheds in this system, but due to the extent of artificial drainage the divides between them are somewhat arbitrary. The creek draining west of Bridgeman is probably artificial and drains what appears to have formerly been a dune-pocketed wetland. However, since it shows no current evidence of pocketing, this watershed was not included as dune-pocketed. There is a distinct landward boundary behind all of these watersheds, most likely an ancient beach ridge. Inland areas behind this drain south to the Galien River or north to the St. Joseph River. Table 6 gives the development, area, and ownership characteristics of each of the dune-pocketed wetlands watersheds in this system.

Table 6. Dune-pocketed wetlands watersheds within the Warren Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Warren Dunes (WD)	10	10	10	875	79	0	21
Thornton Valley 1 (TV1)	10	10	10	1070	100	0	0
Thornton Valley 2 (TV2)	10	10	10	445	100	0	0

V.B Van Buren Dunes System

The southern boundary of the Van Buren Dunes System is located south of Lake Michigan Beach in northern Berrien County. The system extends northward to just north of Van Buren park. From Lake Michigan Beach to the county line, the shoreline landscape is predominantly glacially formed. There are numerous glacial lakes throughout the area. The largest three, Hibbard, Harris, and Jacob's Chapel Lakes, occur adjacent to the dunes. However, by mapping the watershed boundaries and carefully studying the topography it is evident that these are not dune formed. Jacob's Chapel Lake may be artificially deepened due to the construction of the ramps to I-94. Rogers Creek, which drains the area around these lakes, has well developed drainage channels suggesting that at one time this creek was cutting to a lower lake level. The inland topography north of the county line is much flatter, apparently an old lake bed. Upland drainage is much less well developed in the Rogers Creek area, and collects to a broad marshy flat that extends behind the dunes. Mud Lake is the only well defined dune-pocketed catchment. The Mud Lake dune-pocketed wetlands watershed is artificially drained to the south into Rogers Creek and to the north by Brandywine Creek. Nonetheless, it maintains a very marshy character. The watershed to the north, with the Fish Cemetery marked, is developmentally similar to the Mud Lake area, but it is more directly drained by Brandywine Creek. Prior to artificial channelization of Brandywine Creek, the Mud Lake wetland was apparently completely dune-pocketed and it remains essentially so to the present time. Brandywine Creek appears to run under I-94 and Blue Star Highway by a culvert, through an old sandpit excavation and out to Lake Michigan just north of Palisades Park. Dyckman Swamp is a broad, marshy area, artificially drained both to the north and to the south. The shoreline drain zone behind this entire dune system extends nearly four miles inland. It is a very flat area, with almost no drainage development, suggesting that it has been pocketed since the formation of the earliest dunes. Table 7 shows the development, area, and ownership of the dune-pocketed wetlands watersheds in the Van Buren Dunes System.

Table 7. Dune-pocketed wetlands watersheds within the Van Buren Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Mud Lake (ML)	10	7	8	3422	100	0	0
Fish Cemetery (FC)	7	10	9	1884	100	0	0
Dyckman Swamp (DS)	10	7	8	1451	78	0	12

V.C Saugatuck Dunes System

This system extends from just west of Kalamazoo Lake north to Lake Macatawa. Both of these lakes are drowned river mouth type. The shoreline between them is dominated by sand dunes and drains to the Kalamazoo River through Goshorn Creek. North of this drainage system is the Saugatuck Dunes pocketed wetlands watershed, directly behind Saugatuck Dunes State Park. This watershed is relatively small and does not have obvious upland stream channels, but the gradient slopes gradually to the dunes and there is a dune-base catchment (elevation 620'). Apparently dunes formed prior to the development of a stream channel, and the gradient has remained low. Surface drainage is probably connected to ground water at the catchment.

Halfway Creek drains the area to the north, collecting into a dune-base catchment at about 600' elevation. The dunes are weaker here, and apparently drainage has broken through to the big lake. However, upgradient stream channels contain numerous ponded areas, implying a high watertable and poorly developed surface drainage.

Gilligan Lake dune-pocketed wetlands watershed is north of Halfway Creek. The upland is glacial material with rather high topographic relief. Drainage channels have been incised, indicating that this area was probably previously drained by a first-order stream. The apparently shallow catchment is at elevation 610'. Another smaller catchment at the same elevation occurs just to the north of the first, behind a jutting dune. Judging from the degree of drainage development and catchment elevation, this area may have drained to Lake Chicago, but has been blocked by the first dunes formed by the Chippewa drawdown.

The Kelley Lake watershed to the north has similar characteristics, but has been drained to Lake Macatawa. This watershed continues to show evidence of dune pocketing, despite the artificial drainage so we have included it as a landward dune-pocketed wetlands watershed. Table 8 shows the disturbance, area, and ownership characteristics of the dune-pocketed wetlands watersheds within the Van Buren Dunes System.

Table 8. Dune-pocketed wetlands watersheds within the Saugatuck Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Saugatuck Dunes (SD)	3	3	3	545	86	0	14
Gilligan Lake (GL)	7	7	7	1569	100	0	0
Kelley Lake (KL)	7	7	7	1684	100	0	0

V.D Michilinda Dunes System

The Michilinda Dunes begin at Muskrat Lake and end just north of White Lake. However, there are isolated dune features southward along the shore all the way to Muskegon dunes. The landscape is an ancient pro-glacial lake bottom. It is relatively flat, with sandy soils. In this area of shoreline there are numerous ancient stream channels that were apparently incised during the Chippewa drawdown. However, many of the smaller channels are dry due to their porous soils and small watershed area.

Muskrat Lake dune-pocketed wetlands watershed was formed by the same process as Muskegon Lake to the south and Duck and White Lakes to the north. These systems are exemplary drowned river mouth lakes, formed in very erodible substrate. The watershed sizes of the streams are directly related to the size of the catchments they formed. All are apparently groundwater connected. In contrast to the larger lakes watershed, the drainage system collecting to Muskrat Lake was not large enough to maintain the erosive energy needed to maintain an outlet. The channels between Duck Lake and White Lake have even smaller watersheds than Muskrat Lake and therefore did not erode a sufficient channel to form a groundwater connected water body. Table 9 summarizes characteristics of the Michilinda Dunes System.

Table 9. Dune-pocketed wetlands watersheds within the Michilinda Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Muskrat Lake (MS)	3	3	3	3739	100	0	0

V.E Fruitvale Dunes System

This system begins approximately three miles north of the White Lake outlet and ends just inside of the Oceana county line. Although it is relatively close to the Michilinda area, it has developed quite different drainage patterns. The Fruitvale Dunes system was apparently formed over a glacial moraine and has much less permeable soils. The "claybanks" are located east of the Fruitvale System.

The Lehman Road intermittent stream channels formed upon clay substrate but have such small watersheds that surface water goes to ground before reaching the lake, except during large rain storms and in the spring. Lehman Road Creek has a somewhat larger watershed with glacial ponds at the head. It is groundwater connected. The Fruitvale South area is transitional between interdunal and dune-pocketed wetlands. It has not developed an upgradient stream drainage system. Throughout the area there are small dune and shoreline ridge features inland, and between these small wetland areas dominated by buttonbush (Cephalanthus occidentalis) occur over fine textured substrate materials.

The Fruitvale North dune-pocketed wetlands watershed has developed drainage channels that collect to several pockets at the base of the dunes. This is an exemplary dune-pocketed wetlands watershed system (see Figure 10). The drainage pattern in this area contrasts with that of Little Flower Creek to the north, which has approximately the same gradient and watershed size but has drained out to the big lake and therefore has developed much more well defined and deeply cut river channels. Little Flower is contrasted further by Flower Creek, which has a drowned river mouth, evidencing that it drained to Lake Chippewa. Little Flower Creek apparently has cut through to the lake more recently, probably with the erosion of formerly blocking pre-Chippewa dunes by the rising waters of Lake Nipissing. Table 10 summarizes development, size, and ownership characteristics of the dune-pocketed wetlands watersheds of the Fruitvale Dunes System.

Table 10. Dune-pocketed wetlands watersheds within the Fruitvale Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Fruitvale South (FS)	3	3	3	430	100	0	0
Fruitvale North (FN)	5	2	3	265	100	0	0

V.G Little Sable Point South Dunes System

This dune system begins where Whiskey Creek enters Lake Michigan and extends north to the town of Little Point Sable.

The substrate here is similar to that of the Fruitvale system to the south. The southern part of the Little Sable Point system is within Claybanks Township. Whiskey Creek has a very well developed stream drainage system but is now small and intermittent. This stream appears to have cut its channels when it drained to Lake Chippewa. There is no evidence of blockage by pre-Chippewa dunes. Immediately to the north is Long Lake, with a larger watershed and deeper channel. The channel of Long Lake was drowned by the rising waters of Lake Nipissing and then completely pocketed by post-Chippewa (mostly Nipissing) dunes as the lake fell to Algoma and then present levels. "Skinny Lake" between Long and Stony Lakes, developed the same way but its channel has been more filled with encroaching sand. On-site examination indicated that filling by eroding sand is continuing at the western end of this wetland area. Stony Lake is a drowned river mouth of a similar type but with a much larger watershed that has sufficient flow to keep the channel open.

Bigsbie Lake is exemplary of the post-Chippewa dunes pocketed lake and wetlands type (see Figure 10). It is quite similar in its formation process to Muskrat Lake in the Michilinda system.

It has deeply cut channels, apparently of pre-Chippewa age, through very sandy substrate. Now the upper channels are essentially dry, but Bigsbie Lake and a very small wetland at its upper end remain where the channel is deep enough to connect to ground water. The channel was closed off by formation of post-Chippewa dunes.

Table 11 gives index values for disturbance, as well as area and ownership characteristics, for watersheds in the Little Sable Point South System.

Table 11. Dune-pocketed wetlands watersheds within the Little Sable Point South Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Long Lake (LL)	5	4	5	1122	100	0	0
Skinny Lake (SL)	2	3	3	864	100	0	0
Bigsbie Lake (BL)	4	3	3	1000	100	0	0

V.H Big Sable Point/Hamlin Lake/Nordhouse Dunes System

The formation of Nordhouse Dunes is due primarily to longshore drift that began forming spits across the mouth of the Big Sable River during Lake Chicago. The cause of those spits is most likely shallow offshore water or a moraine which sent the southerly currents lakeward and then deposited most of the sand on the north side of the river mouth. When Lake Chicago dropped in elevation first to Main Algonquin of Michigan and then to Lake Chippewa, that sand formed an extensive dune field along the shore to the north, extending approximately to the Manistee-Mason county line. The first pre-Chippewa dune ridge pocketed Nordhouse Lake, the Spartina Marsh area, Porter Creek, and Cooper Creek. That ridge (improperly name "Nipissing trail ridge" on the Forest Service trail maps in this area) probably extended well lakeward during the Chippewa drawdown. The Big Sable River cut down during the Chippewa period, as did many of the other streams that presently enter Hamlin Lake. The bay-mouth bar that formed offshore giving rise to Hamlin Lake has preserved several of these downcut river mouths from alteration by dune formation and other shoreline processes along the eastern shore of Hamlin Lake. Upper Hamlin Lake is a drowned river mouth.

When levels rose back to Nipissing (605') most of the pre-Chippewa dunes were eroded by waves and reworked as longshore drift, forming a large baymouth bar in front of the Big Sable

River. The downcutting of the Big Sable and other streams that formerly entered the big lake at this point is evidenced by the deeply cut river mouth channels along the east side of Hamlin Lake. Reverse eddy currents in Lake Nipissing apparently carried sand along the shore from the north by longshore drift, and deposited it in the south on the Big Sable point. That process eroded the northern part of this once more extensive dune field and eventually "unpocketed" some of the formerly blocked drainage systems. Cooper Creek was probably opened in this way. It has developed some drainage channels near the lake but remains weakly channeled. Porter Creek was probably opened even more recently and has a very poorly developed drainage system. Immediately south of Porter Creek the shoreline is expanding. Therefore, watersheds lying behind the dunes south of this point (i.e. Spartina Marsh watershed and Nordhouse Lake watershed) remained pocketed.

- Lost Lakes appears to be a system of large interdunal lakes that formed between the first Algonquin ridge and the succeeding post-Chippewa dunes. These later dunes were formed to the west on the developing bar platform, leaving a low area which is presently occupied by the Lost Lakes, between these two sets of dunes. The lakes formed on the inner margins of bay-mouth bar lakes should be studied further. These constitute a unique formation type that has not been specifically identified heretofore.

We have recently described the Big Sable Point/Hamlin Lake/Nordhouse Dunes Environmental System in much more detail

(Goff et al, 1987). Table 12 shows the disturbance, area, and ownership characteristics of the dune-pocketed wetlands watersheds in the Big Sable Point/Hamlin Lake/Nordhouse Dunes System.

Table 12. Dune-pocketed wetlands watersheds within the Big Sable Point/Hamlin Lake/Nordhouse Dunes System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
Nordhouse Lake (NL)	2	1	1	938	0	100	0
Spartina Marsh (SM)	1	2	2	1181	0	100	0

V.I County Line Road Watersheds

This is a small dune area between Gurney Creek and Magoon Creek. Apparently both watersheds drained to Lake Chippewa, although the southern section most likely flowed into Gurney Creek before entering the big lake. The character of the natural drainage systems in the area has been altered by artificial drainage. There are two watersheds, weakly connected along the base of the dunes. The first, County Line Road North, originates in springs that are recharged from the glacial hills to the east. It flows westward to the base of the dunes and then north along the dunes for about a mile before it enters the big lake. From the stream course it is obvious that the dunes have had an effect. However, on-site inspection shows this to be a cedar swamp area with a clearly flowing stream throughout its entire length. Other than the fact that the cedar swamp is unusually wet (see Appendix I), there is no evidence of pocketing by the dunes.

The southern watershed unit apparently also receives water from the east but is separated from the headwaters of the northern watershed unit by a dividing ridge. At the base of the dunes it is difficult to distinguish these two units. However, whereas the stream draining the northern units turns to the north, the southern unit apparently slopes slightly to the south from this point so water moves southward, eventually pocketing against the dunes.

At the catchment of this southern unit there is evidence of dredging and other disturbance. Apparently a channel was dredged across the low dunes several decades ago in an attempt to drain this pocketed wetland area. A road was built across the southwestern tip of the wetland at the base of the dunes. Dead, woody wetland vegetation throughout the southern watershed unit shows the effect of draining the area. Then, probably quite recently, the culvert collapsed (it is not now functioning) and the lowermost portion of the area re-flooded. There is now evidence of extreme seasonal fluctuation in water level (see Appendix I). Development, size, and ownership characteristics of the County Line South dune-pocketed wetlands watershed area are given in Table 13.

Table 13. Dune-pocketed wetlands watersheds within the County Line Road System -- development, area, and ownership. Development index values range from 0 (undeveloped) to 10 (highly developed) -- see Table 1 in Section II for an explanation of scale values (U = Upland; L = Lowland/Catchment; W = Watershed weighted mean). Ownership percentages are given for Private (P), Federal (F), and State (S).

Dune-pocketed wetlands watershed name and code	Degree of Development			Area (acres)	Ownership percent		
	U	L	W		P	F	S
County Line South (CL)	3	10	8	315	100	0	0

V.J Disturbance Analysis

One of the motives for this study was to find out how "unique" the dune-pocketed wetlands watersheds in the Nordhouse Dunes System are in comparison to other examples of this land type occurring elsewhere along the shoreline. We had stated that the two dune-pocketed wetlands watersheds in the Nordhouse area were the largest relatively undisturbed examples in public ownership. We found during the course of this study that while there are other exemplary areas, none are as undisturbed as Nordhouse.

Figure 8 shows a frequency plot of the disturbance index values for the eighteen dune-pocketed wetlands watersheds included in the study.

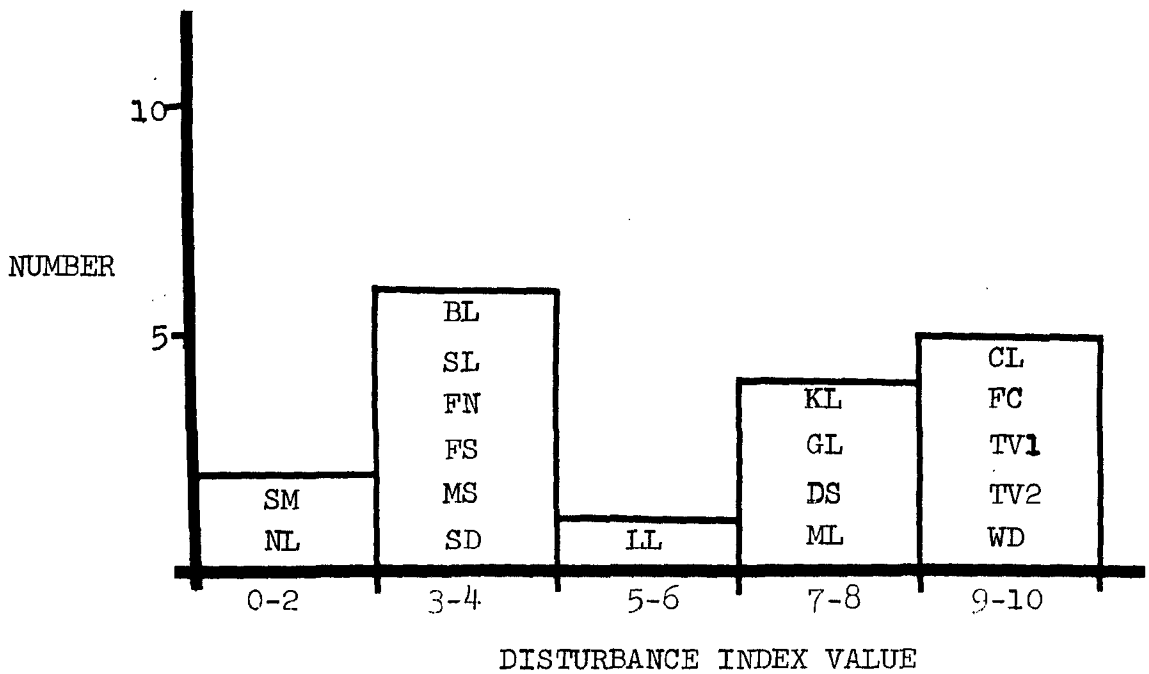


Figure 8. Disturbance index values of eighteen dune-pocketed wetlands watersheds along the eastern Lake Michigan shoreline. Table 3 gives the names corresponding to the abbreviations indicated inside each bar of the graph. Watersheds having an index value of 3-4 should be considered candidates for special management.

VI. ORDINATION AND CLASSIFICATION OF DUNE-POCKETED WETLANDS WATERSHEDS

In order to better understand the similarities and differences among the dune-pocketed wetlands watersheds, we prepared several graphical presentations. The most meaningful of these shows the distribution of the dune-pocketed wetlands watersheds within a simple ordination (graph) of watershed area (logarithmic scale) and topographic relief (Figure 9). These two factors are related to the development of the drainage systems and to their surface gradient and erosive energy. Presentation of the watersheds in this form provides a framework for interpretation of relationships among them and for development of hypotheses regarding their development.

The most obvious pattern in this ordination is the peaked distribution. This can be accounted for by two effects, both resulting from the relationship between topographic relief, watershed area, and the erosive energy available to cut through any impedance at the mouth of the watershed (e.g. dunes). None of the dune-pocketed watersheds included in the study are found in the upper left sector of the ordination because the very steep gradient implied by this combination of watershed size and topographic relief would normally erode back and enlarge the watershed. No dune-pocketed watersheds are found in the upper right sector of the ordination because the erosive energy of watersheds that large

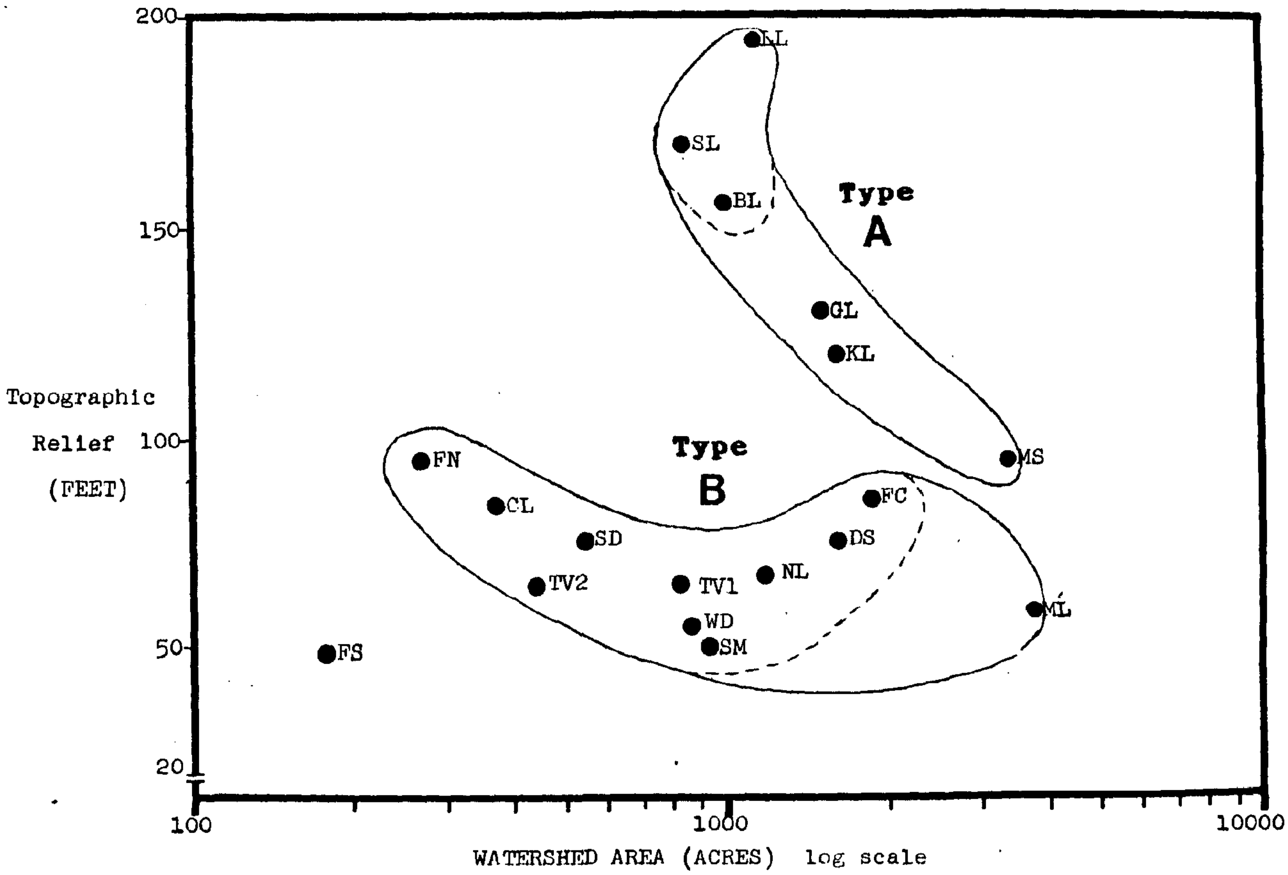


Figure 9. Area/topographic relief ordination of dune-pocketed wetlands watersheds along the eastern Lake Michigan shoreline. Dashed lines enclose initial clusters. Solid lines enclose types finally determined.

and with that much relief cut through the dunes and did not remain pocketed. Had they been included, many interdunal wetland basins would have fallen in the upper left portion of this ordination and many direct drain streams and drowned river mouth lake watersheds along the shoreline would have fallen in the upper right portion.

Most of the dune-pocketed wetlands watersheds have between 50 and 100 feet of total relief. A few have more than 100 feet. Comparison of the position of the watersheds within this simple ordination, particularly their topography, led us to initially identify two clusters as possibly distinct types (Figure 9 -- dashed lines). The placement of watersheds that did not fit conveniently into one of these clusters required further reexamination of drainage characteristics.

The single low relief watershed at the lower left of the ordination is a small area that occurs on the landward edge of the dunes. Careful examination of its mapped topography and drainage in relation to topographic characteristics of the surrounding landscape, as well as field examination, convinced us that it was an "borderline" dune-pocketed wetland, transitional to a interdunal area. To avoid overlap between this study and work on the interdunal wetlands underway by the Michigan Natural Features Inventory, we did not generally consider interdunal wetlands. Several watersheds (not shown) were examined and analyzed because they were thought to be small examples of the landward dune-pocketed wetlands watershed type. Landward dunal features associated with their formation were not obvious from published information sources. However, they lack the internal lakeward drainage patterns associated with dune-pocketed wetlands and in every instance upon field examination we found them to be associated on all sides with dune features. The process of their formation is essentially interdunal. We have retained only one, as an example of the transitional type.

Examination of the high relief watersheds (Type A) shows localized relatively deeply incised channels suggesting a different process of origin from the watersheds lower in the ordination. The watershed of Muskrat Lake Watershed (MS) has a similar pattern of relief to those higher in the graph even though its total amount of topographic relief is not as great. Based on its pattern of relief it was included in Type A. Gilligan Lake Watershed (GL) and Kelley Lake Watershed (KL) occur within the Saugatuck Dune System. South of them is the Halfway Creek somewhat impeded stream drainage system which is topographically similar in general pattern to GL and KL. None of these three watersheds are as dramatically channeled as those of the other watersheds in Type A, but based on their position in the ordination as well as the presence of channels more deeply incised than those typical of watersheds in Type B, these were included in the Type A cluster. They are actually intermediate in their topographic pattern and should be studied further. Figure 9 (solid lines) shows the two types finally established (with Fruitvale South shown as an exception to either type).

We postulate that the Type B watersheds were all pocketed by more ancient pre-Lake Chippewa (mostly Algonquin) dunes, and have remained pocketed ever since, whereas the Type A watersheds were unimpeded during the Chippewa low water stage. The enhanced downcutting of channels during the Chippewa drawdown accounts for the deeply cut ravines characteristic of Type B watersheds.

Figure 10 shows panoramic views of typical examples of these two dune-pocketed wetlands watershed types, and Figure 11 shows the corresponding topographic and drainage patterns. The upper panorama shows much of the Bigsbie Lake watershed. The lake is a permanent feature. There is little lowland. In the upper, shallow part of the lake, emergent aquatic vegetation is found, but there is almost no shrub carr or sedge meadow development. The well drained upland gives way abruptly to the dammed lake. This pattern is typical of Type A watersheds. According to our hypothesis the channel now occupied by Bigsbie Lake was deeply cut during the Chippewa low water stage. With rising lake levels its channel was flooded in a manner similar to that of drowned river mouths. With the drop in water level from Lake Nipissing (605') to present (580'), dunes eventually pocketed the lake. Dune sand is slowly encroaching on the lower end of the lake and the upper end is gradually filling in due to erosion of the adjacent hills (which are veneered with older dune sand).


A


B

Figure 10. Panoramic views of two contrasting Dune-Pocketed Wetlands watershed systems.

Bigsbee Lake Dune-Pocketed Wetlands watershed was dammed by Nipissing or more recent dunes (Type A, upper photograph). Its deep channel was cut during the Chippewa drawdown when it was an unimpeded stream.

Fruitvale North Dune-Pocketed Wetlands watershed (Type B, bottom photograph) is a low relief watershed pocketed in ancient times by Algonquin or older dunes prior to the Chippewa drawdown.

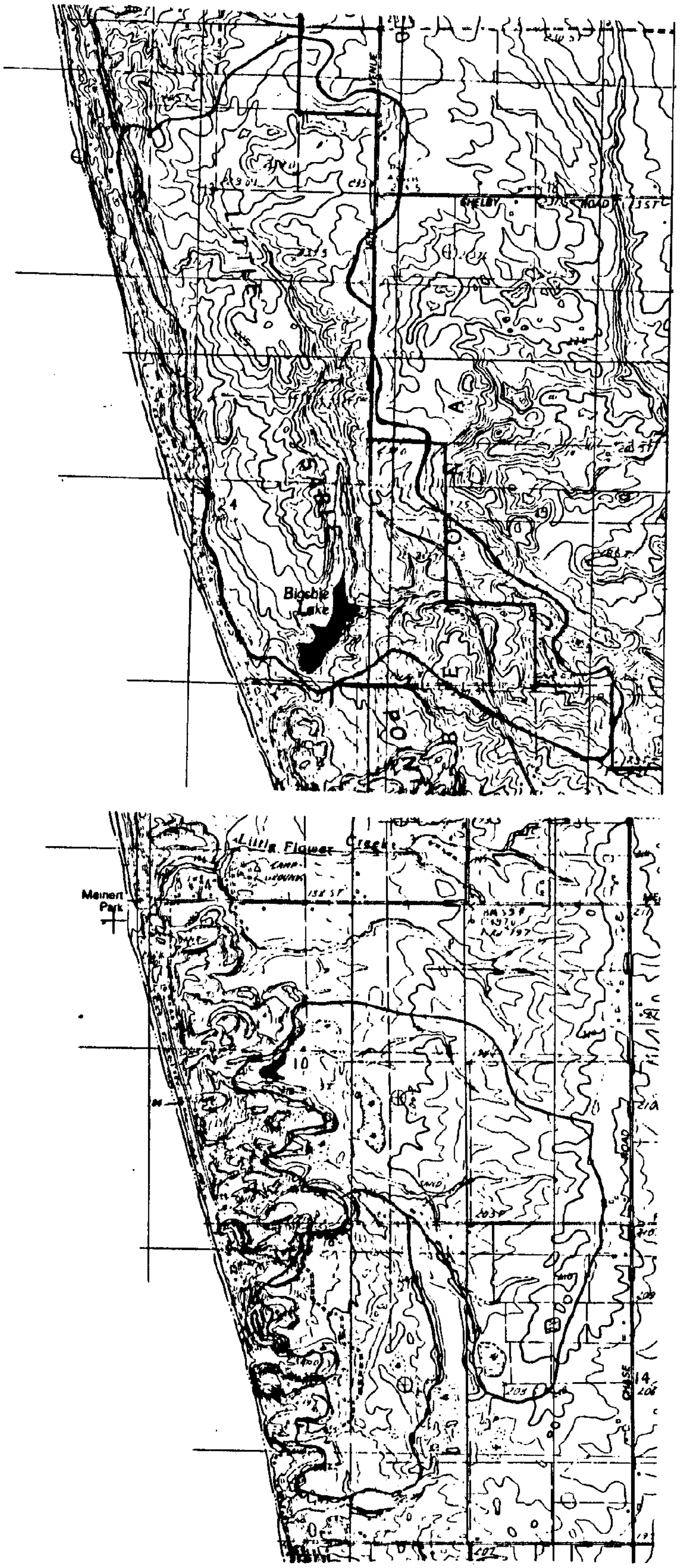


Figure 11. Topographic maps of the Bigsbie Lake Type A dune-pocketed wetlands watershed area (upper map), and the Fruitvale North Type B dune-pocketed wetlands watershed area (lower map). Topographic relief in much greater in the Type A watershed.

The watershed of the Fruitvale North dune-pocketed system (lower panorama) has been pocketed by dunes since before the Chippewa stage (pocketing dunes in this case are apparently of early Algonquin age). Throughout the upgradient watershed (off the picture to the upper right) the landscape is characterized by low, poorly drained areas. Although it does slope gently toward Lake Michigan and eventually forms a catchment at the base of the dunes, drainage channels have developed only very weakly in this watershed. Apparently during the time of maximum drainage channel development for many of the other watersheds along the shoreline, this area (and other areas of pre-Chippewa dune pocketing) were protected from the downcutting process. Not only are they pocketed by the present dunes of the Lake Michigan shoreline, Type B drainage systems have been geomorphologically preserved by dunes formed very early in post-glacial time.

VII. DISCUSSION

This study was initiated in response to a land management issue. While the study was underway the Nordhouse Dunes area in northern Mason County was officially declared a wilderness, the only area so designated in the lower peninsula. At the time of this writing there are lawsuits in process that question the authority of the government to limit hydrocarbon development within that area. As we have conducted ecological studies of the Nordhouse dunes and the surrounding landscape during the past two years, we have become aware that this landscape was developmentally a single system. The dunes block drainage, forming dune-pocketed wetlands stretching eastward clear to the watershed divide. Moreover, the drainage systems in these dune-pocketed areas are very poorly developed. In contrast to other shoreline areas, blocking dunes stopped the normal process of stream downcutting, effectively preserving the drainage system in the form that it had soon after the glacier retreated. It was this realization that led us to explore several questions, "How extensive are such dune-pocketed wetland watersheds?" "How did they form, and how are they related to other types of drainage systems?" "Where do they occur and what are their present-day characteristics?"

These and related questions have led us into an exploration of the surface drainage systems of the eastern Lake Michigan shoreline. When we started the study we harbored some doubts about the significance of this previously undescribed type of watershed. Now we are completely convinced that these landward dune-pocketed wetland watersheds form a set of dune-related systems that is of limited extent and deserving of special management consideration. The distinction between the two major types of dune-pocketed wetlands recognized in this study -- high relief systems formed by more recent (Nipissing) dune development, and the flatter, older systems where drainage has been blocked since the early Algonquin recession to Lake Chippewa -- may provide important clues for more general understanding of wetland drainage systems in other areas.

One deficiency of this study needs to be pointed out. We recognize that the study would have been greatly improved if we had been able to deal more effectively with groundwater. Soil and substrate characteristics vary regionally as well as locally along the shoreline. Patterns of variation in substrate and groundwater processes may account for some of the distinctions observed between the drainage systems studied. But the time available and the scope of study simply did not permit us to include much substrate and groundwater information.

Our original hypothesis was that few if any of the drainage systems that presently cut through the dunes were pocketed at an earlier time. This reasoning was based on the assumption that the pre-Chippewa dunes that are presently found along the shoreline constitute virtually the complete extent of such dunes. If so, and if a given stream along the shore is unimpeded now, it must have always drained. Gradually we have come to realize that this is not necessarily so. In some areas older dunes that previously blocked stream drainage appear to have been eroded away on the lakeward side by subsequent rising water levels. Comparison of the degree of downcutting in watersheds that are pre-Chippewa dune-pocketed (e.g. Nordhouse Lake, Spartina Marsh) and adjacent watersheds of presently unimpeded direct drain streams (e.g. Porter Creek), suggests that these presently unimpeded streams emptying to Lake Michigan were formerly impeded, at least to some degree.

Consideration of the conditions that would have been likely during the time when the lake level was dropping from Main Algonquin of Michigan (605') to Chippewa (230') further suggests that extensive dune fields may have formed in some presently offshore areas. The initial drop to Main Algonquin of Michigan was abrupt, due to opening of the Straits of Mackinaw. This probably resulted in shoreline and dune development several hundred yards west of the position of the present shoreline. Then the lake continued to drop as the till was eroded in the Straits until another relatively stable water level was achieved corresponding to the level of bedrock in the Straits. Another shoreline and dune system can be postulated corresponding to this pause in the receding lake level. Finally, as the soft breccia bedrock was eroded away, the level continued to drop in the northern part of the basin to a low of approximately 230'. The southern portion of the basin did not drop below 336' due to elevated land (Valders moraine), now beneath the lake, near Grand Haven. Extensive dune systems may have formed over much of the land area laid bare by the receding levels of Lake Chippewa. It is reasonable to suppose that the pre-Chippewa dunes presently occurring along the lakeshore would have been substantially wider and more extensive than at present during this time, resulting in more extensive pocketing of drainage.

The channels of streams that cut through the pre-Chippewa dunes were eroded much more deeply than those that remained impeded. During the Chippewa drawdown, the position of the receding lakeshore was dependent on the bottom contours. In general, the southern third of the lake (south of the Valders moraine) had a more gentle gradient than the northern shore. This gradient needs to be considered when estimating stream channel cutting. Where the lake was shallow for a long distance out from the shore, the gradient may not have increased when the waters receded even though the total relief of the watershed would have.

As the water levels rose, all pre-Chippewa dunes below water level were washed away by wave action, leaving only the oldest, most landward portions of the Main Algonquin of Michigan and some older dunes. It is probable that few of the formerly pre-Chippewa dune-pocketed drainage systems remained impeded throughout this period (essentially only the eleven that we have identified as Type B). However, because the erosional gradient had been reduced, there was little change in form of these drainage systems.

As the lake receded once more from 605' to the present 580' level, Nipissing and Algoma dunes formed by reworking the sand of the previously more extensive pre-Chippewa dunes. In many instances, drainage channels that had breached the dunes during the 605' minimal dune stage remained open through the developing Nipissing dunes. Post-Chippewa dunes did form at the mouth of some drainage systems during this time, such as those on the south side of Little Sable Point where the lower ends of the pre-Nipissing drainage channels were cut below lake level. Although we treated these as dune-pocketed wetland watersheds, we recognized that they were different from other drainage systems in this class. They are really drowned river mouths that have subsequently been blocked by post-Chippewa dune development over the filled channel. These are all very small watersheds for the amount of relief that they display, so there was relatively little runoff to breach the developing post-Chippewa dunes.

Understanding is the key to effective management of our resources. It is also vitally needed for realistic preservation, which is actually a form of management. What to save and what to develop are issues that land managers face constantly -- how to control development that does occur in order to preserve our natural heritage and yet use the resources of the earth in a manner consistent with the total well-being of present and future generations. In order to make responsible decisions regarding these resources it is necessary to understand them and to have an adequate inventory. Both dunes and wetlands are currently of great concern. Both are important. The dunes are a geologic resource formed under very different conditions than those of the present day. They cannot be replaced. Some wetlands are geomorphically and developmentally related to the dunes and to the whole shoreline process through geologic time. Seen in this context the shorelines, dunes, and watersheds form a series of developmentally, structurally, and functionally integrated systems along eastern Lake Michigan.

VIII. SUMMARY

The Chippewa drawdown, a major lowering of Lake Michigan between Lakes Chicago and Nipissing, was very significant in the development of shoreline drainage systems. This event, in combination with littoral drift and dune formation, explains much of the present character of the eastern Lake Michigan shoreline and adjacent inland areas. We have described the development of several different types of drainage systems occurring along the shoreline and have inventoried the dune-pocketed wetlands watershed type and two subtypes (pre-Chippewa and post-Chippewa). In the area south of significant crustal rebound, running from the Indiana/Michigan state line north to Frankfort in Benzie County, these landlocked watersheds are found behind the dunes in several areas. We recognized and described eighteen dune-pocketed wetlands watersheds. Field data were collected on the vegetation and other characteristics of several representative sites of each drainage system type. Watershed boundaries of all dune-pocketed wetlands watersheds have been traced onto USGS topographic base maps in a form suitable for digitizing and entry into the Michigan Resource Information System.

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APPENDIX I.

Notes on the vegetation and ecology of wetlands sites examined during the summer of 1987. Examples of several different types of watersheds are included, with descriptive information, maps, and photographs.

APPENDIX I
SITE-BY-SITE VEGETATION NOTES

The vegetation and site descriptions in this Appendix were developed during the summer of 1987. The purpose of the site examinations was to assist in the development of a shoreline drainage system classification system. Three different levels of field examination were employed.

Level I: General Scouting -- The purpose of this level of observation was to gain general impressions of the wetland watershed areas by driving perimeter roads or hiking through each area scouted. Notes on drainage, topography, soils, cover types and development were made and referenced to the USGS topographic maps. Significant features were documented by narrative field notes and photographically.

Level II: -- Specific Site Description -- The purpose of this level of observation was to locate a predetermined candidate site of interest (e.g. a catchment basin, drainage divide, upgradient wetland, etc.) and describe its characteristics. Photos were taken in most instances. A narrative description was written to summarize the area's significance. Vegetation cover type was noted and dominant species were recorded. Initially, based on the hypothesis that certain variables would prove to be important in distinguishing and understanding these wetlands, each was ranked subjectively on three scales using vegetation community composition and other indicators: (A) a mineral enrichment scale [0 = ombrotrophic to 10 = minerotrophic]; (B) a closure/succession scale [0 = open water to 10 = lowland forest], and (C) a surface water variability scale [0 = constant seasonal water level to 10 = highly variable water level between early spring and late summer]. The basis of these scales is described more fully in the "Wetland Vegetational Processes" section of the full report (Section IV).

Level III -- Vegetation/Species Survey -- This level of observation was made for certain sites that seemed to typify the wetland drainage type classes. It consisted of a Level II observation plus a timed meander species search within the general location of the identified site. Rather than keying unknown specimens on site, they were collected, labelled and later pressed and identified.

We were particularly interested in characterizing the dune-pocketed wetlands watersheds. However, we recognized early that it would not be possible within the time and cost of this study to complete a systematic field examination of all examples of this watershed type. Indeed, at that time we were not even sure which of the wetland areas occurring along the shoreline area were members of the logical set termed "dune-pocketed wetlands watersheds". In order to make such a determination it was necessary for us to study examples of several of the wetland watersheds, observe and record their characteristics and then use this data in conjunction with map studies and other information to formulate a comprehensive classification. Several dune-pocketed wetlands watersheds are included among the watersheds examined in the field. Because we could not field examine all of the sites along the entire shoreline within the time available, we concentrated on a section of the shoreline from the Fruitvale Dunes in northern Oceana County north to Bar Lake Swamp in Manistee County. This shoreline section contains a range of variation in shoreline drainage system types, as well as dune-pocketed wetlands watershed types. The following site descriptions are presented in order from south to north. The names and code designations are the same as those used in Section V of the main report. Watershed boundary maps are included.

A.1 Fruitvale South Dune-Pocketed Wetlands Watershed -- Photo 1 shows the vegetation structure in a catchment at the base of the dunes in the Fruitvale South dune-pocketed wetlands watershed system. This catchment (Map 1, location 1) is an elongated area (several hundred meters long and only about 100 meters wide) with its long axis oriented north and south parallel to the face of the dunes. The photograph was taken viewing westward across the wetland toward a large blowout ridge which appears at the horizon of the photo. This dune is apparently eroding and encroaching on the dune-pocketed wetland marsh. The marsh is a sedge meadow-shrub carr combination. Soils are organic at the surface and become progressively wetter toward the center of the wetland where there is standing water covered with duckweed (Lemna minor). Dominant shrubs are Cephalanthus occidentalis (up to aproximately 5 inches in diameter), Ilex verticillata, Cornus amomum, Spiraea tomentosa, Salix lucida, and Salix discolor. Herbaceous species include Iris virginica, Lycopus uniflorus, Ludwigia palustris, Scirpus cyperinus, Carex crinita, Typha latifolia, Dulichium arundinaceum, Leerzia oryzoides, Bidens sp., Osmunda cinnamomea, Osmunda regalis, Thelypteris palustris, and Calamogrostis canadensis. Around the margins of the wetland, Salix nigra occurs, with occasional Populus tremuloides and Acer rubrum.

Photo 2 shows the ponding that occurs in the southern end of the Fruitvale South dune-pocketed wetlands area. The pond (Map 1, location 2) contains yellow water lily (Nuphar variegata). The dominant shrub cover around the margin of the open water is button bush (Cephalanthus occidentalis). Other species in this ecotone zone are Polygonum amphibium, Polygonum hydropiperoides, and Carex crinita. There are fish in the pond (suggesting that it is a relatively permanent feature) even though it is only a couple of feet deep. The wetland is blocked on the lower end by a dune ridge.

Photo 3 shows the structure of vegetation in a small wetland area (Map 1, location 3) to the east of a low ridge separating the catchment at the base of the high dunes from inland areas. Throughout the area numerous wetland shrub carrs and marshes similar to this example are found. These are separated from one another by low ridges, possibly inland dune features. Apparently the lowland forest/shrub carr vegetation that previously occurred in many of these areas was killed by flooding perhaps twenty-thirty years ago. There are dead Thuja occidentalis and Cephalanthus occidentalis in most of them. Low sprouts of Cephalanthus are now becoming re-established and succession to this and other shrub species is occurring. Other species include Cicuta maculata, Bidens sp., Ludwigia palustris, Ilex verticillata, Salix discolor, Solanum dulcamara, Sium suave, Lycopus asper, Osmunda cinnamomea, Osmunda regalis, Thelypteris palustris, Carex sp., Calamogrostis canadensis, and Iris virginica. There is one small Thuja occidentalis and a few Nyssa sylvatica trees along the edge of the wetland area; otherwise lowland forest is limited. The upland forest comes right down to the edge of the sedge meadow/shrub carr. The surrounding forest is comprised primarily of hemlock, red maple, red oak, white pine, black oak, black gum, and yellow birch.

Photo 4 shows a successionally more advanced shrub carr area (Map 1, location 4) presently succeeding to lowland forest. Dominant species are Salix discolor, Salix lucida, Pinus strobus, Acer rubrum, and Betula papyrifera.

A.2 Horseshoe Lake wetland area -- The Horeshoe Lake catchment area (Map 1, location 5) located relatively far inland in the Fruitvale Dunes System was examined and found to be of glacial origin -- part to the Fruitvale Creek watershed. This wetland displays aquatic to upland zonation and also a gradient from ombrotrophic peatland type vegetation in its upper (northern) end (Photo 5a), to a much more minerotrophic aquatic and marsh vegetation in its lower end (Photo 5b). The northern end of the Horseshoe Lake wetland area is less influenced by mineral-rich groundwater than the lower end. Consequently, the vegetation is more ombrotrophic, with Chamaedaphne calyculata, Osmunda cinnamomea, and Scirpus cyperinus dominant. Around the outer edges, buttonbush (Cephalanthus occidentalis) occurs.
In the deepest part of the lower portion there is standing water perhaps two feet deep, with Nuphar variegata and Potamogeton sp. Around the edge of the open water there is Polygonum amphibium and then a zone of Scirpus cyperinus dominated sedge meadow. Cephalanthus occidentalis, Chamaedaphne calyculata, and Rosa palustris form an outer zone of shrub cover. At the edge of the forest a narrow zone of Nyssa sylvatica occurs, and this gives way quickly to upland species including Pinus strobus, Acer rubrum, Quercus borealis, and Fagus grandifolia.

To the east of the Horseshoe Lake wetland another small minerotrophic wetland area was examined. Species recorded in the wetter part of this area include Typha latifolia, Scirpus cyperinus, Osmunda cinnamomea, Matuccia strutheriopteris, Impatiens pallida, Carex lacustris, Glyceria striata, Ilex verticillata, Salix discolor, Cephalanthus occidentalis, Betula papyrifera, Thuja occidentalis, and Tsuga canadensis. Around the edges there is Acer rubrum, Punus strobus, Fraxinus americana, Prunus serotina, and Betula lutea. This area is wetter at the surface than the leatherleaf portion of the Horseshoe Lake wetland located immediately to the west across a separating ridge. After careful examination of the Horseshoe Lake area including several marshes, we concluded that it is a glacial landscape with no direct relationship to the dunes to the west.

A.3 Fruitvale North Dune-Pocketed Wetlands Watershed -- This watershed is located immediately to the north of the Fruitvale south dune-pocketed wetlands area (in fact the two could be considered as subunits of a single watershed). Fruitvale north is an exemplary dune-pocketed wetlands watershed of the pre-Chippewa type (Type B, see main report). Figure 10 of the main report presents a panoramic view of the catchment of the watershed and Map 1 (location 6) shows its location. Species in the primary catchment area include: Bidens sp., Polygonum hydropiperoides, Pilea pumila, Carex sp., Polygonum amphibium, Fraxinus pensylvanica, Hypericum punctatum, Salix petiolaris, Cyperus esula, Mentha arvensis, Cephalanthus occidentalis, Ludwigia palustris, Hordeum jubatum, Salix nigra, Eragrostis spectabilis, Eleocharis elliptica, Rorippa islandica, Cornus amomum, Eupatorium perfoliatum, and Salix lucida.

Upgradient from this primary catchmemt area there is a series of low shrub carr and marsh openings separated by low dunes or beach ridges (Map 1, location 7). Some of these have open water surrounded by buttonbush (Cephalanthus occidentalis) and other shrubs (Photo 6a) while others are more marshy, with cattail (Typha latifolia) and a variety of sedges, other herbaceous species, and shrubs (Photo 6b). Many of the species listed above within the primary catchment area also occur in these upgradient marshes. Additional species recorded include: Sassafras albidum, Iris virginica, Cornus stolonifera, Ilex verticillata, Quercus borealis, Juncus effusus, Salix discolor, Scirpus cyperinus, and Acer rubrum.

A.4 Winston Road Wetland Area -- South of Long Lake we examined a wetland area (Map 2, location 1) that is located close to the shoreline but is apparently a headwater area for an inland unimpeded stream drainage system (Flower Creek). Casual observation of the flora and vegetation revealed no differences between this and dune-associated wetland areas. Photo 7 shows the general appearance of the open shrub carr vegetation community in this area.

A.5 Long Lake -- The Long Lake dune-pocketed catchment is shown on Map 2 (location 2). Viewing eastward up Long Lake (Photo 8) a large bed of yellow water lily (Nuphar variegata) is observable at the eastern end of the open water zone. East of that is cattail (Typha latifolia) and a variety of sedges, grasses (e.g. Calamogrostis canadensis) and herbaceous species forming a marsh zone. Around the edges of the basin there is a narrow strip of lowland trees (e.g. Salix nigra) and shrubs (e.g. Cephalanthus occidentalis). The upland forest cover is Pinus strobus, Quercus borealis, and Quercus velutina. A noteworthy characteristic of this landlocked lake/wetland is the narrow lowland strip. Vegetation goes abruptly from catchment (open water, open marsh) to uplands.

A.6 Skinny Lake -- "Skinny" Lake is a wetland located in a long east-west trough that is blocked by dunes on its western end (Map 2, location 3). It is apparently similar in its genesis to both Long Lake to the south and Bigsbie Lake to the north, but was a shallower ravine and is more filled in. The catchment is narrow and there is abrupt transition to upland, with almost no lowland zone (Photo 9). Species recorded include: Lemma minor, Calamogrostis canadensis, Betula papyrifera, Typha latifolia, Scirpus cyperinus, Sparganium eurycarpum, Scirpus validus, Nuphar variegata, Polygonum amphibium, Carex stricta and Sassafras albidum.

A.7 Bigsbie Lake Dune-Pocketed Watershed -- The Bigsbie Lake watershed is a classical example of a Type A (post-Chippewa) dune-pocketed area (see Figure 10 in main report). Map 3 (location 1) shows the location, and Photo 10 shows the wetland area at the head of the lake. The lake is between glacial hills but is blocked on its west end by dunes. Species present include Salix petiolaris, Salix discolor, Thelypteris palustris, Cephalanthus occidentalis, Nuphar variegata, Najas flexilis, Calamogrostis canadensis, and Typha latifolia. There are a few Salix nigra trees around the edge of the lake and wetland, but the open catchment essentially gives way directly to upland forest (Fagus grandifolia, Acer rubrum, Tsuga canadensis, Betula lutea, Quercus borealis, etc.) with no lowland zone present.

A.8 Little Silver Lake -- The Little Silver Lake area (Map 4, location 1) was investigated as a possible dune-pocketed wetland. There is a small minerotrophic pond. Although the entire area is sandy, there is a thin layer of muck at the soil surface. Blue herons frequent the area. Little Silver Lake is separated from Silver Lake by a low dune ridge. These were apparently a single water body at one time. The shallow open water of Little Silver Lake is surrounded by a marshy sedge meadow zone and then shrub carr (Photo 11). Species recorded include: Nuphar variegata, Bidens sp., Juncus effusus, Carex stricta, Lythrum salicaria, Sparganium eurycarpum, Leerzia oryzoides, Rosa palustris, Cephalanthus occidentalis, Salix discolor, Salix lucida, Onoclea sensibilis, Osmunda cinnamomea, Prunus serotina, Populus tremuloides, and Quercus velutina. Little Silver Lake is best considered as an interdunal area -- part of the Silver Lake baymouth bar complex.

A.9 Cedar Point Park Wetland -- Cedar Point Park wetland area in Section 4 - TI5N - RI8W (Map 5, location 1) was examined as a possibly dune-associated wetland area. However, upon field inspection and further map analysis this area appears to be a glacial lake which just happens to occur in the shoreline zone. A species list is given in Table 1. It is a small, relatively species poor, bog lake (Photo 12) surrounded by leatherleaf

Table 1. Species list from Cedar Point Park wetland area sampled August 5, 1987 by F. Glenn Goff. The list includes species occurring in a wet forest pocket (Photo 12) in the glacial (non-dunal) landscape in Section 4 - T15N - R18W. Sample employed the timed meander-search procedure (Goff, Dawson and Rochow, 1982) with a total search time of 30 minutes.

Acer rubrum
Aronia melanocarpa
Betula papyrifera
Brassenia schreberi
Carex canescens
Carex oliosperma
Cephalanthus occidentalis
Chamaedaphne calculata
Dulichium arundinaceum
Eleocharis elliptica
Eleocharis erythropoda
Gaylussacia baccata
Hypericum ellipticun
Iris virginica
Juncus canadensis
Lycopus uniflorus
Mattucia strutheriopteris
Nemopanthus mucronata
Nuphar variagata
Nyssa sylvatica
Pinus resinosa
Pinus strobus
Populus tremuloides
Pteridium aquilinum
Quercus ellipsoidalis
Ranunculus sp.
Scirpus cyperinus
Sphagnum sp.
Triadenum virginicum
Utricularia minor
Vaccinium angustifolium

(Chamaedaphne calyculata), tamarack (Larix laricina), and white pine (Pinus strobus). There is buttonbush (Cephalanthus occidentalis) and black gum (Nyssa sylvatica) around the outer edge of the mote.

A.10 Ridge Road Wetland -- The small wetland areas just southeast of the Pentwater Dune System (Map 5, location 2) are of limited extent and mostly successionally advanced to the stage of lowland forest, although small patches of more open shrub and occasional sedge-fern vegetation are also found. This area was included in the study because it superficially resembles much of the impeded drainage lowland forest in the Fruitvale area to the south, the Nordhouse Dunes tract to the north, and elsewhere along the Lake Michigan shoreline. It is included as an example of a type of vegetation that forms in poorly drained glacial areas where seasonal flooding is sufficient to retard forest development but not sufficient to set succession back to the shrub carr or sedge meadow stadge.

Photo 13 shows the general character of the vegetation in the Ridge Road Wetland area. The photo shows Jim Lively standing in a young lowland forest of Acer rubrum and Fraxinus pensylvanica. Trees are mostly small and unhealthy -- the result of periodic flooding. The canopy is densely closed in some areas and open in others. In open patches there are usually direct signs of seasonal flooding (e.g. leaves matted by flood waters, debris stranded on lower portions of trees and shrubs, dried algae crust on the soil surface). Soils are generally black and high in organic matter to several inches in depth. In these open areas the herbaceous flora is typical of northern wet hardwood forests, including: Osmunda cinnamomea, Calamogrostis canadensis, Lycopus uniflorus, Viola conspersa, Carex intumescens, Osmunda regalis, Onoclea sensibilis, Thelypteris palustris, Glyceria striata, Carex crinita, Carex canescens, Scutellaria lateriflora, and Coptis trifolia. Shrub species occuring more abundantly in the wetter openings include: Ilex verticillata, Aronia melanocarpa, Alnus rugosa, Spiraea alba, and Nemopanthus mucronata. Old hemlock (Tsuga canadensis) and yellow birch (Betula lutea) trees occurring on slightly higher topography throughout the area suggest that despite its second-growth appearance, the vegetation mosaic of this area represents a stable plant community at equilibrium with its environment -- i.e. with seasonal flooding setting back succession periodically in the lower, wetter areas to mainatin the community in a late shrub carr -- early lowland forest successional stage. This is not a dune-pocketed wetlands area.

A.11 Spartina Marsh -- The vegetation and ecology of the Nordhouse Dunes area has been extensively described elsewhere (Hazlett, 1986, Wells and Thompson 1984, Goff, et al 1986, 1987). This area has recently been officially designated as a wilderness area, the only wilderness in the Lower Peninsula. It was on the basis of our earlier review and investigations of the landward dunes associated with the Nordhouse Dunes that we recognized the existence of the category of wetlands termed "landward barrier dune-pocketed wetlands", the principal focus of this study and inventory. However, while we recognize the existence of two completely pocketed wetland watersheds within the Nordhouse Dunes subsystem (Goff, Skoog and Lively, 1987) (Map 6, locations 1 and 2), because of the extensive work already done in the Nordhouse System and owing to the more general objectives of this study, we examined the flora of only the catchment portion of one of these (Map 6, location 2) -- the Spartina Marsh dune-pocketed watershed catchment area near the campground of the Lake Michigan Recreation Area. Photo 14 shows the structure of vegetation in this catchment area. Photo 14A shows Jim Lively standing in the grassy sedge meadow near the center of the catchment (indicating a nearly dead clump of Salix petiolaris). Clumps of dead or near dead Salix petiolaris appear on the right side of the photo and are found throughout the area. In photograph 14B Jim is indicating the seasonal high water mark that is obvious on trees throughout this area. In the early spring, water accumulates in this catchment to a depth of about one meter. Then, apparently by seepage into the dune sand, the water level drops slowly but steadily until, by mid- to late-summer the area is completely dry. This area, typical of such dune-pocketed wetland sites, acts as a natural runoff catchment basin. It is surrounded by open xeric forest with jack pine (Pinus banksiana), Hill's oak (Quercus ellipsoidalis), trembling aspen (Populus tremuloides), and other species typical of northern Michigan dry forests. Table 2 provides a species list for the Spartina Marsh catchment area. Only twenty-nine species were found.

A.12 Cooper Creek Road -- This is a small leatherleaf (Chamaedaphne calyculata) peatland area (Map 6, location 3). Because of its location, apparently on the inland margin of the high dunes, we examined it as a potential dune-pocketed wetland. The entire wetland (peatland) area is only about 2 acres in extent. It is surrounded on all sides by dunes although the dunes are lower on the eastern side. We called it "semi-interdunal" in the field and now consider it an interdunal type. A list of the species found in the area is included in Table 3. The mineral enrichment value was estimated at 1.0; the wetland succession value at 5.5; and the water constancy value at 8.0. Photo 15 shows the general appearance of the vegetation in the area. It is apparently a small paludified peatland area. White pine (Pinus strobus) grows throughout.

A.13 Manistee-Mason County Line Watersheds -- Two contrasting basins that occur behind the barrier dunes in the vicinity of the Mason/Manistee County Line (Map 7, locations 1 and 2) depict very well the contrast between groundwater recharged ("spring-fed") cedar swamp vegetation and vegetation of the landlocked, seasonally flooded dune-pocketed wetlands catchment. The northernmost of these contrasting watersheds (Map 7, location 1) has an outlet to Lake Michigan (Map 7, location 4). The outlet stream flows westward from the surrounding glacial hills to the front of the dunes and then turns to the north, finally entering Lake Michigan. Although the stream course has been altered by the

Table 2. Species list from the Spartina Marsh area in the Big Sable -- Nordhouse Dunes System. The list includes species occurring in the seasonally inundated catchment area at the base of the barrier dunes. By F. Glenn Goff, July 30, 1987. This species list was composed using the timed meander-search procedure (Goff, Dawson and Rochow, 1982) with a total search time of 30 minutes.

Andropogon gerardi
Aster lateriflorus
Calamogrostis canadensis
Carex buxbaumii
Carex cryptolepis
Carex lanuginosa
Eleocharis acicularis
Eleocharis elliptica
Fraxinus americana
Fraxinus pensylvanica
Hypericum kalmianum
Hypericum punctatum
Juncus acuminatus
Juncus canadensis
Lycopus uniflorus
Mentha arvensis
Oenothera perennis
Panicum implicatum
Panicum virgatum
Pilea pumila
Populus tremuloides
Salix petiolaris
Sassafras albidum
Scirpus cyperinus
Scutellaria lateriflorus
Spartina pectinata
Spiraea alba
Thelypteris palustris
Viola lanceolata

Table 3. Species list from Cooper Creek Road peatland -- a small leatherleaf peatland pocket. By F. Glenn Goff, August 5, 1987. This species list was composed using the timed meander-search procedure (Goff, Dawson and Rochow, 1982) with a total search time of 30 minutes.

Acer rubrum
Aronia melanocarpa
Betula papyrifera
Carex sp.
Chamaedaphne calyculata
Eriophorum spissum
Gaylussacia baccata
Glyceria canadensis
Ilex verticillata
Juncus nodosus
Larix laricina
Mathicia strutheriopteris
Menyanthes trifoliata
Nemopauthus mucronata
Pinus resinosa
Pinus strobus
Quercus borealis
Sphagnum sp.
Triadenum virginanum
Vaccinium angustifolium
Vaccinium macrocarpon
Vaccinum myrtelloides

dunes, the vegetation is cedar swamp throughout and there is little evidence of seasonal flooding, although there is apparently some impedance of flow due to the dunes.

Photo 16 (a & b) show the vegetation conditions that are typical of this area. Photo 16a shows Jim Lively standing in one of the headwater spring areas. The vegetation here is predominantly tamarack (Larix laricina) woods with cattail (Typha latifolia) dominated sedge-meadow areas in the more open areas. Conditions lower in the watershed are depicted by Photo 16b. This is a typical northern Michigan wet cedar swamp community. The moisture supply appears to be predominantly from groundwater and is apparently relatively constant through the year. Although the area is wetter during the spring months, it does not become seasonally flooded as does the dune-pocketed wetlands catchment areas. If flooding does occur it is apparently temporary. Soils are wet, mucky, and in places there is shallow standing water at the surface with floating duckweed (Lemna minor). There are many down cedar trees and profuse white cedar regeneration suggesting a low deer population. The stream flows westward to the base of the dunes, then it meanders northward for over a half-mile to its confluence with Lake Michigan. Table 4 provides a listing of the species found in the cedar swamp area.

To the south there is a low divide separating the cedar swamp area from a dune-pocketed catchment area (Map 7, location 2) that apparently drains to the south. These two watershed units merge together at the base of the dunes (Map 7, location 3), making it difficult to tell exactly where the divide occurs. Proceeding southward along the landward base of the dunes, cedar swamp gradually gives way to shrub carr vegetation dominated by Salix petiolaris and then to an open area that was obviously flooded during the spring and earlier in the summer. Photo 17a shows Jim Lively standing in the formerly flooded area of the catchment, and Photo 17b is a closeup of the ground surface showing snail shells and dragonfly larvae -- evidence of the earlier flooded condition. Vegetation in the open area consists primarily of patches of Polygonum amphibium and Proserpinaca palustris. There are also small patches of sedge meadow within the shrub carr. A species list made in the shrub carr, sedge, open meadow, and catchment area is provided as Table 5. This area is apparently flooded in the spring to a depth of a meter or more. Almost all of the water that it receives obviously comes in the form of surface runoff. Due to the lack of groundwater influence, the area dries by mid- to late-summer. This annual cycle of flooding and drying, which appears to be typical of the post-Chippewa barrier dune-pocketed wetlands, provides suitable habitat for relatively few species, many of which are amphibious plants (e.g. Polygonum amphibium, Polygonum hydropiperoides, Proserpinaca palustris) and facultative wetland species (e.g. Rorippa islandica, Lysimachia terrestris, Lobelia cardinalis). The almost ubiquitous occurrence of Salix petiolaris in the dune pocketed wetland catchment areas is also noteworthy. Farther to the south in the state this species becomes less frequent and buttonbush (Cephalanthus occidentalis)

Table 4. Species list from the spring fed cedar swamp watershed in the Mason-Manistee County Line Dune System. By F. Glenn Goff, July 30, 1987. This species list was composed using the timed meander-search procedure (Goff, Dawson and Rochow, 1982) with a total search time of 30 minutes.

Acer rubrum
Alnus rugosa
Betula lutea
Bidens cernua
Caltha palustris
Cardamine pensylvanica
Carex bebbii
Carex disperma
Carex hystericina
Cinna latifolia
Coptis trifolia
Cornus stolonifera
Epilobium ciliatus
Eupatorium maculatum
Fraxinus nigra
Gaultheria hispidula
Geum rivale
Glyceria striata
Ilex verticillata
Impatiens pallida
Juncus brachycephalus
Juncus canadensis
Larix laricina
Lemna minor
Lobelia cardinalis
Lobelia siphilitica
Ludwigia palustris
Lycopus asper
Maianthemum canadense
Mentha arvensis
Onoclea sensibilis
Osmunda regalis
Pilea pumila
Ranunculus abortivus
Rhamnus alnifolia
Ribes americanum
Rubus pubescens
Scutellaria lateriflora
Solanum dulcamara
Solidago rugosa
Thelypteris palustris
Thuja occidentalis
Trientalis borealis
Vaccinium angustifolium
Viola incognita
Viola pallens

Table 5. Species list for a dune-pocketed wetland area along the southwestern edge of Mason/Manistee County Line Dune System. The species list was made by F. Glenn Goff on July 30, 1987. It was compiled using the timed meander-search procedure of Goff, Dawson and Rochow (1982) and represents a 30 minute search period. Search includes margins as well as central portion of the catchment area.

Agrostis alba
Alnus rugosa
Asclepias incarnata
Betula papyrifera
Carex bebbii
Carex lacustris
Carex stricta
Chamaedaphne calyculata
Cornus stolonifera
Epilobium ciliatum
Eupatorium maculatum
Eupatorium perfoliatum
Glyceria canadensis
Glyceria striata
Ilex verticillata
Iris virginica
Larix laricina
Lobelia cardinalis
Lycopus asper
Lysimachis terrestris
Osmunda regalis
Poa compressa
Polygonum amphibium
Polygonum hydropiperoides
Proserpinaca palustris
Quercus borealis
Rorippa islandica
Rosa palustris
Rubus pubescens
Salix discolor
Salix lucida
Salix nigra
Salix petiolaris
Scirpus cyperinus
Solidago altissima
Thelypteris palustris
Thuja occidentalis
Vitis riparia

becomes more common, but Salix petiolaris was found in nearly every dune pocketed catchment that we examined.

A.14 Bar Lake Swamp -- Bar Lake Swamp illustrates the contrast in vegetation types between a groundwater maintained ("spring fed") swamp (Map 8, location 1) and a highly seasonal, principally surface water recharged dune-associated wetland (Map 8, location 2). Bar Lake Swamp was formed when postglacial uplift of the land drained a former bay-mouth bar lake. Along the eastern side of the swamp glacial hills of reddish unassorted till rise abruptly above the swamp. On the west side Bar Lake Swamp abuts the barrier dunes.

A fresh-water stream runs from south to north along the eastern side of the swamp. This stream is apparently maintained by groundwater recharge from the hills to the east. The general appearance of the cedar swamp community along this stream is shown in Photo 18. This is a typical cedar (Thuja occidentalis) lowland forest. Soils are muck. Numerous small openings occur in the forest cover and in these patches a rich understory flora of boreal species is found. A species list made on July 29, 1987 in the cedar swamp area is provided as Table 6.

Along the western edge of Bar Lake Swamp, areas of sedge meadow and shrub carr occur at the base of high dune ridges. Like the pre-Chippewa dune-pocketed wetlands, these wetland sedge meadow -- shrub carr areas are apparently seasonally flooded to a depth of a meter or more judging from water marks and debris stranded on trees and shrubs by the receding water. Although this was formed as a bay-mouth bar lake system, along its western side, at the base of the dunes, it is similar to the pre-Chippewa dune-pocketed wetlands areas farther south. Like the dune-pocketed wetlands, dammed by highly porous dune sands that impede water movement only temporarily, this area de-waters during the summer and may become very dry in the late summer months of low rainfall years. The open herbaceous and shrub cover typical of such wetland areas is the result of periodic disturbance flooding and drought and is in marked contrast to the more successionally advanced lowland forest cover found on the east side of the swamp where moisture levels are more constant. The vegetation here is apparently a stable community type, in the sense that it is at equilibrium with the edaphic and disturbance conditions typical of the landscape it occupies -- i.e., it is predictably maintained at a relatively early stage of succession by frequent natural extremes in water level and site moisture conditions.

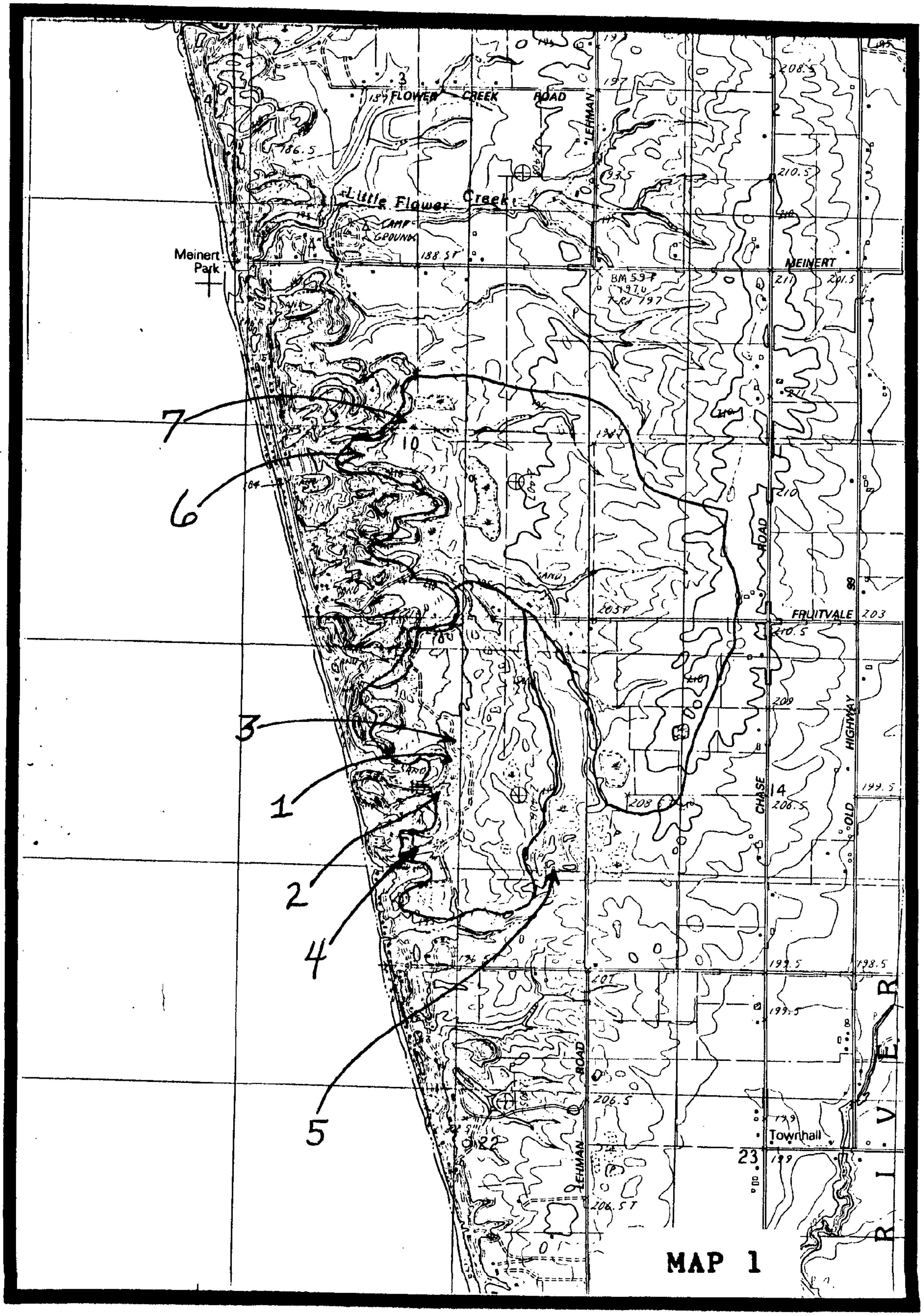
Photo 19 shows the structure of the plant community. Jim Lively is standing at the boundary between the open, sedge dominated area in the foreground and the shrub (principally Salix petiolaris) dominated area in the background. A few cattail (Typha latifolia) fruiting stalks are shown on the left. Cattails are rare in the area, apparently because of the very dry conditions that may prevail in late summer. The species list for the dune-pocketed wetland areas (Table 7) contrasts sharply with the species found in the spring-fed swamp area to the east.

Table 6. Species list from the spring fed cedar swamp portion (east side) of Bar Lake Swamp, by F. Glenn Goff, July 29, 1987. This species list was composed using the timed meander-search procedure (Goff, Dawson and Rochow, 1982) with a total search time of 30 minutes.

Abies balsamea
Acer rubrum
Acer saccharum
Adiantum pedatum
Alnus rugosa
Amelanchier canadensis
Anthoxanthum odoratum
Aralia racemosa
Arisaema triphyllum
Aster lateriflorus
Aster macrophyllus
Athyrium filix-femina
Berberis thunbergii
Betula lutea
Betula papyrifera
Carex arctata
Carex disperma
Carex leptonervia
Carex retrorsa
Cerasteum vulgatum
Cinna latifolia
Circaea alpina
Circaea quadrisulcata
Clintonia borealis
Coptis trifolia
Cornus alternifolia
Cryptotaenia canadensis
Cystopteris bulbifera
Dryopteris disjuncta
Dryopteris spinulosa
Epilobium coloratum
Epipactus helleborine
Fagus grandifolia
Fragaria virginiana
Fraxinus americana
Fraxinus nigra
Galium triflorum
Geum canadense
Glyceria striata
Impatiens pallida
Lonicera dioica
Lycopus asper
Maianthemum canandese
Mitchella repens
Mitella nuda
Onoclea sensibilis
Osmunda cinnamomea
Osmunda regalis
Pilea pumila
Polygonatum biflorum
Prunella vulgaris
Prunus serotina
Pyrola secunda
Quercus borealis
Ranunculus recurvatus
Ribes hirtellum
Rubus pubescens
Rubus strigosus
Sambucus canadensis
Solidago patula
Solidago rugosa
Thelypteris palustris
Thuja occidentalis
Tilia americana
Trientalis borealis
Tsuga canadensis
Ulmus americana
Veronica americana
Viola incognita

Table 7. Species list for a dune-pocketed wetland area along the western edge of Bar Lake Swamp, by F. Glenn Goff, July 29, 1987. The list was compiled using the timed meander-search procedure of Goff, Dawson and Rochow (1982) and represents a 30 minute search period.

Acer rubrum
Alnus rugosa
Asclepias incarnata
Aster lateriflorus
Boehmeria cylindrica
Calamogrostis canadensis
Carex alata
Carex aquatilis
Carex interior
Carex lacustris
Carex rosea
Carex sp.
Carex stricta
Cicuta bulbifera
Cornus amomum
Cornus stolonifera
Dulichium arundinaceum
Eleocharis smallii
Eupatorium maculatum
Eupatorium maculatum
Fraxinus americana
Fraxinus pensylvanica
Galium concinnum
Galium tinctorium
Glyceria striata
Hypericum ellipticum
Ilex verticillata
Iris virginica
Juncus canadensis
Juncus effusus
Leerzia oryzoides
Lobelia cardinalis
Ludwigia palustris
Lycopus asper
Lycopus uniflorus
Myrica gale
Onoclea sensibilis
Osmunda regalis
Pilea pumila
Polygonum amphibium
Polygonum hydropiperoides
Populus tremuloides
Potentilla palustris
Proserpinaca palustris
Rhamnus alnifolia
Rhus radicans
Rosa palustris
Rubus pubescens
Rumex obtusifolius
Salix discolor
Salix glaucophylloides
Salix nigra
Salix petiolaris
Scirpus fluviatilis
Scirpus pendulus
Scutellaria lateriflora
Smilicina stellata
Taraxacum officinale
Thelypertis palustris
Triadenum virginianum
Typha latifolia
Ulmus americana
Vitis riparia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Little Flower Creek
CAMP GROUND
Meinert Park
MEINERT
BM 597
FRUITVALE
CHASE
ROAD
OLD HIGHWAY
Townhall
LEHMAN ROAD
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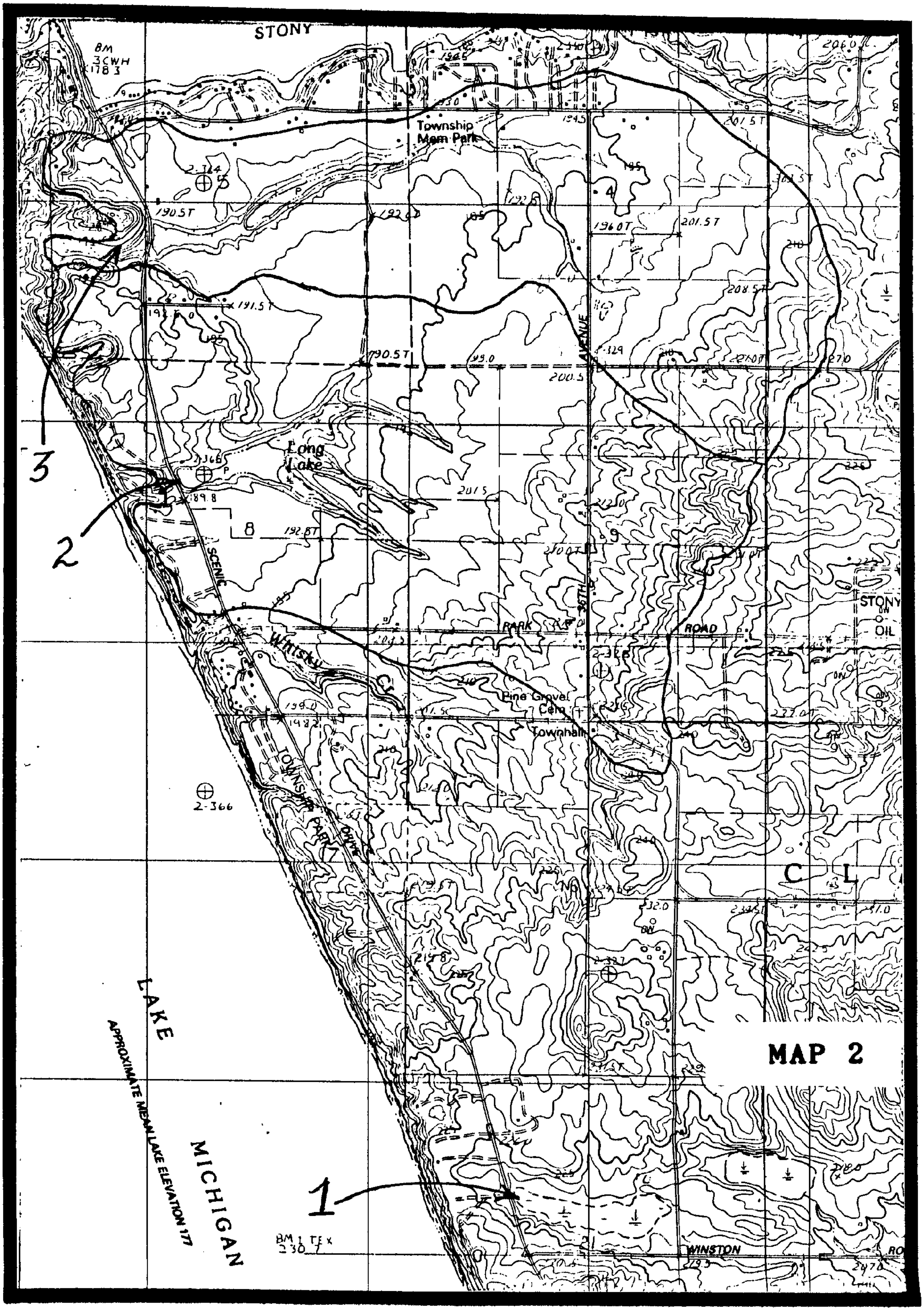
7

MAP 1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Lake
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Whisky
PARK
ROAD
Pine Grove
Cem
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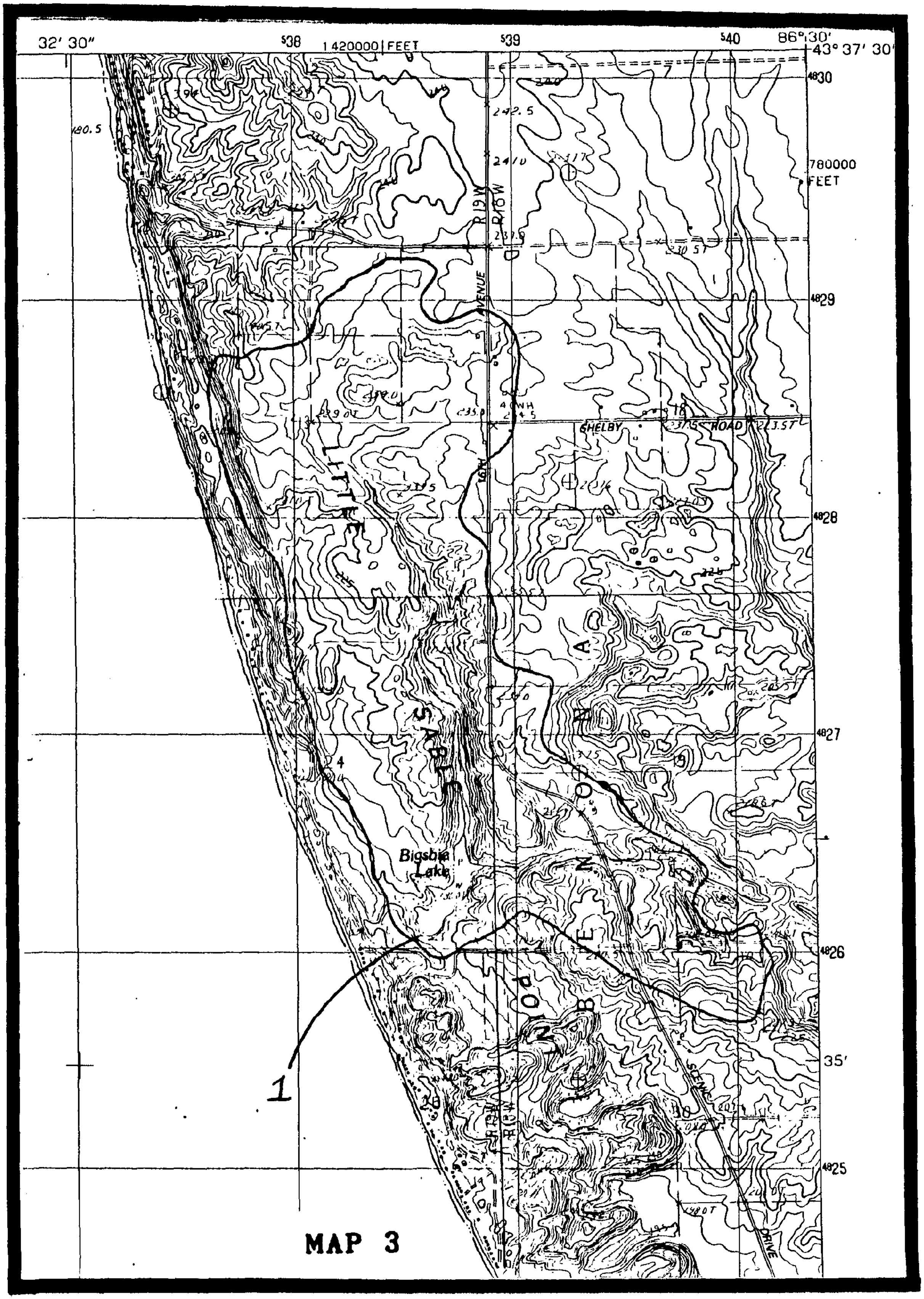
LAKE
MICHIGAN
APPROXIMATE MEAN LAKE ELEVATION 177
WINSTON
MAP 2
1
2
3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SABLE
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Bigsbia
Lake
SCENIC
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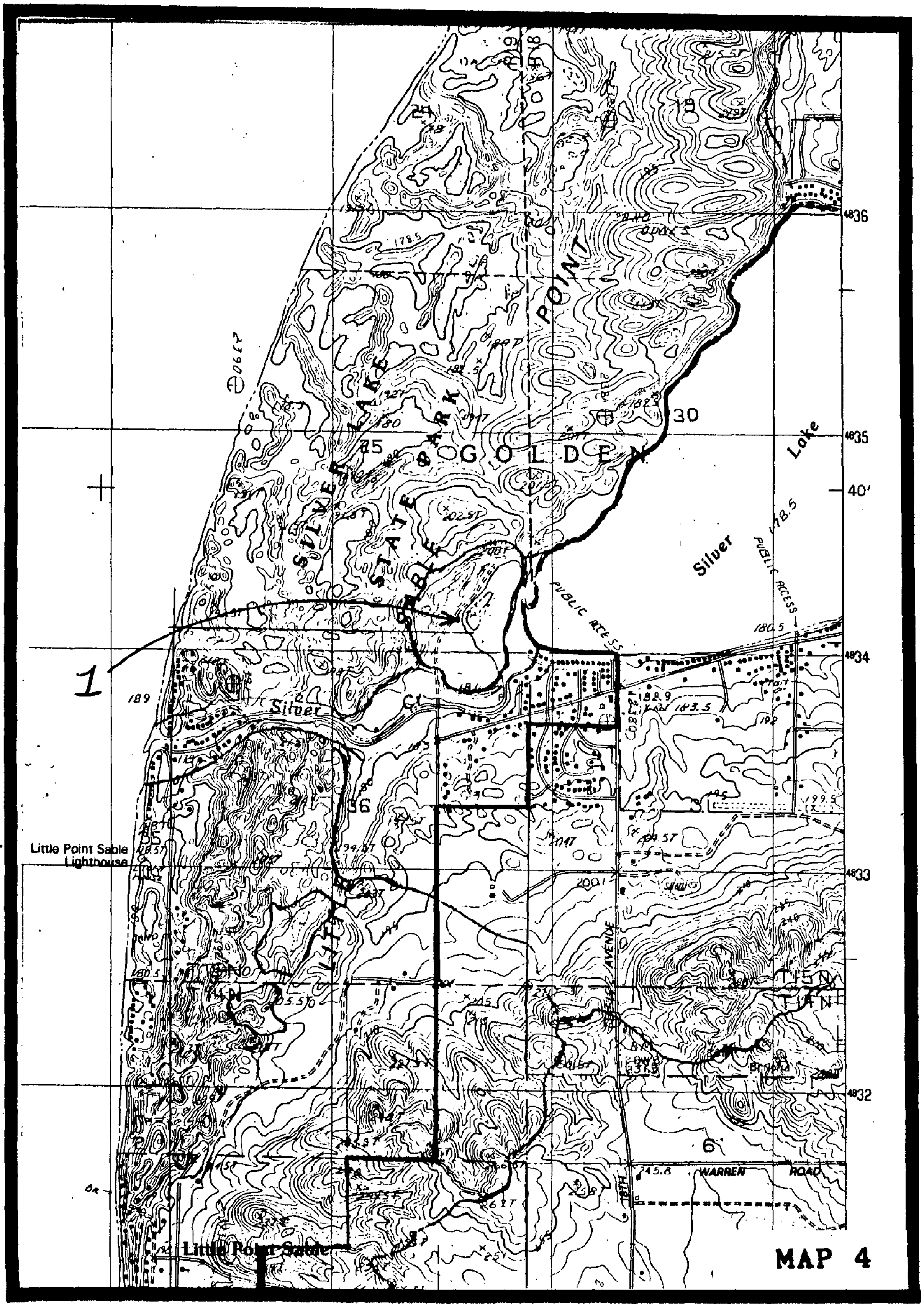
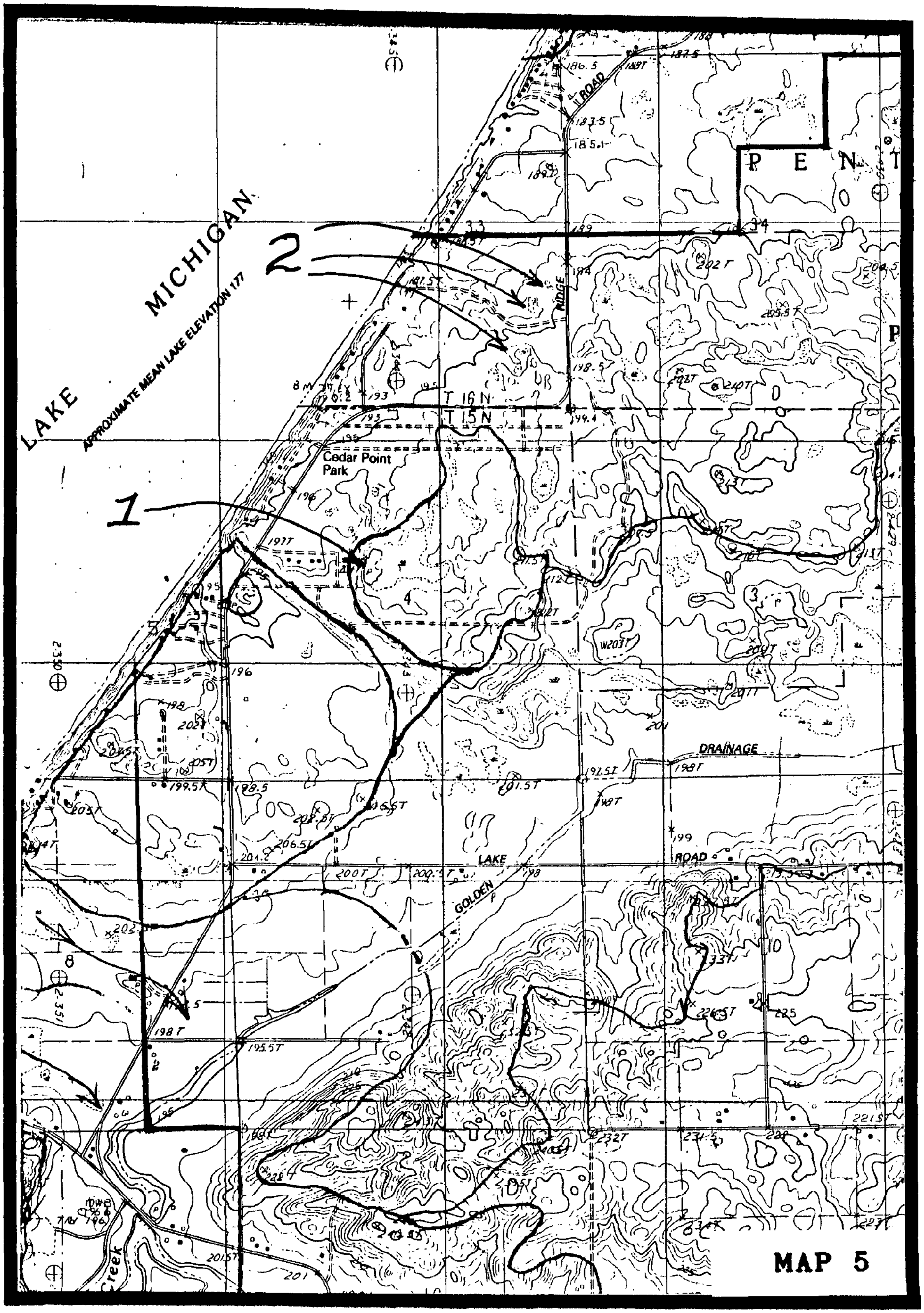
1

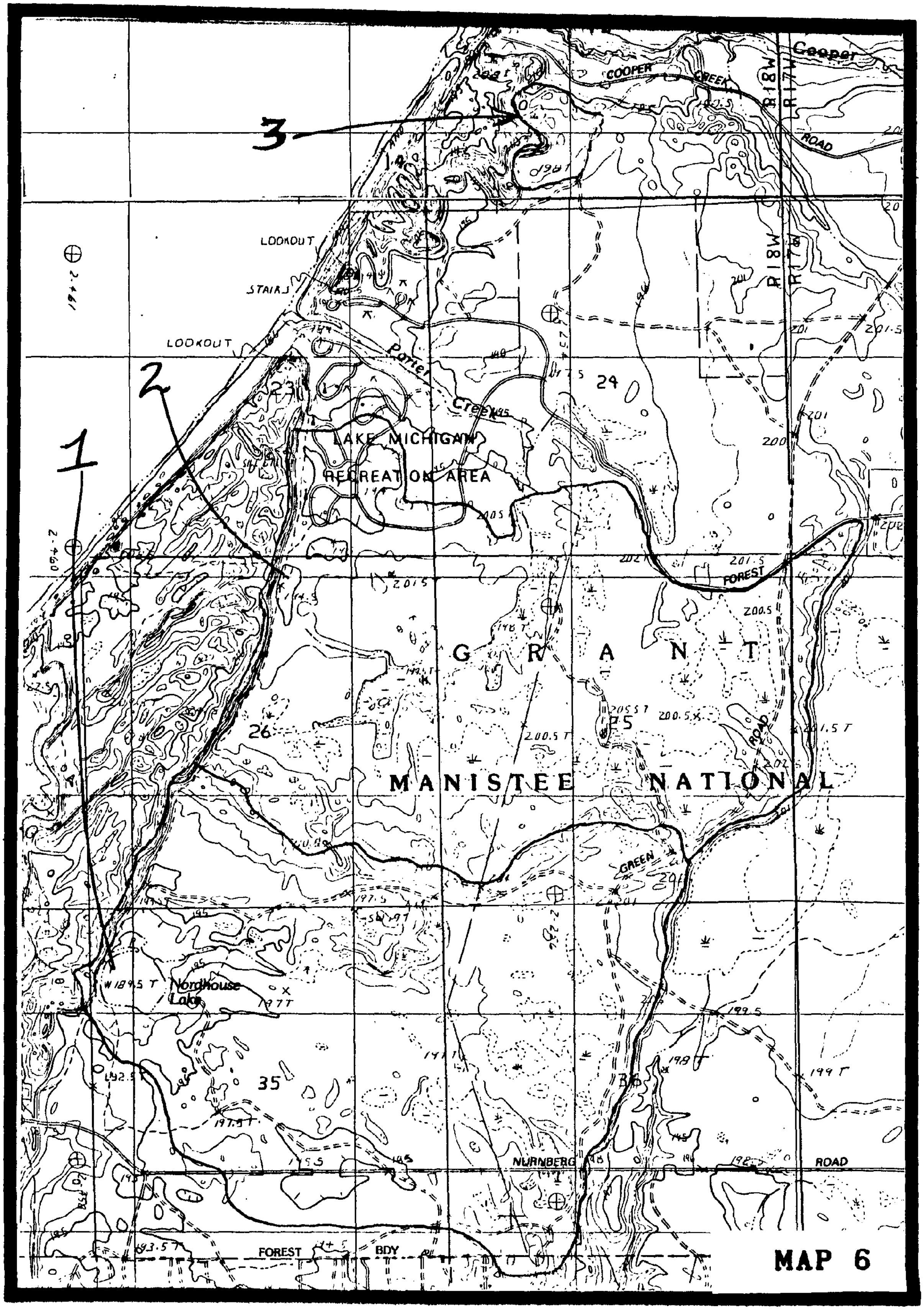
MAP 3



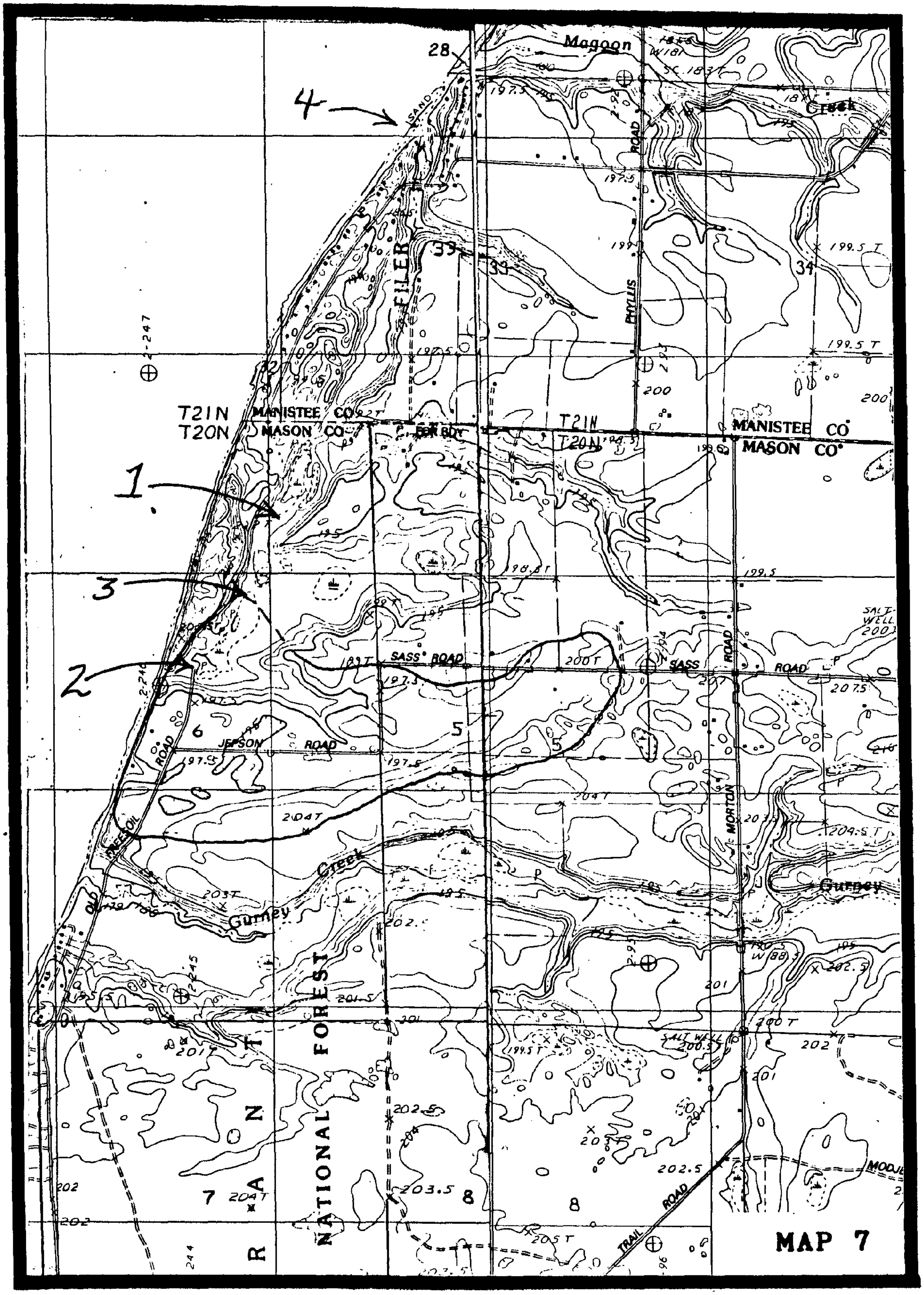
SILVER LAKE STATE PARK
GOLDEN
POINT
Silver Lake
PUBLIC ACCESS
Silver
Little Point Sable Lighthouse
Little Point Sable
WARREN
ROAD
AVENUE
T15N
T14N
MAP 4


LAKE MICHIGAN
APPROXIMATE MEAN LAKE ELEVATION 177
Cedar Point Park
T 16 N
T 15 N
RIDGE
ROAD
DRAINAGE
LAKE
ROAD
GOLDEN
Creek
P E N
1
2

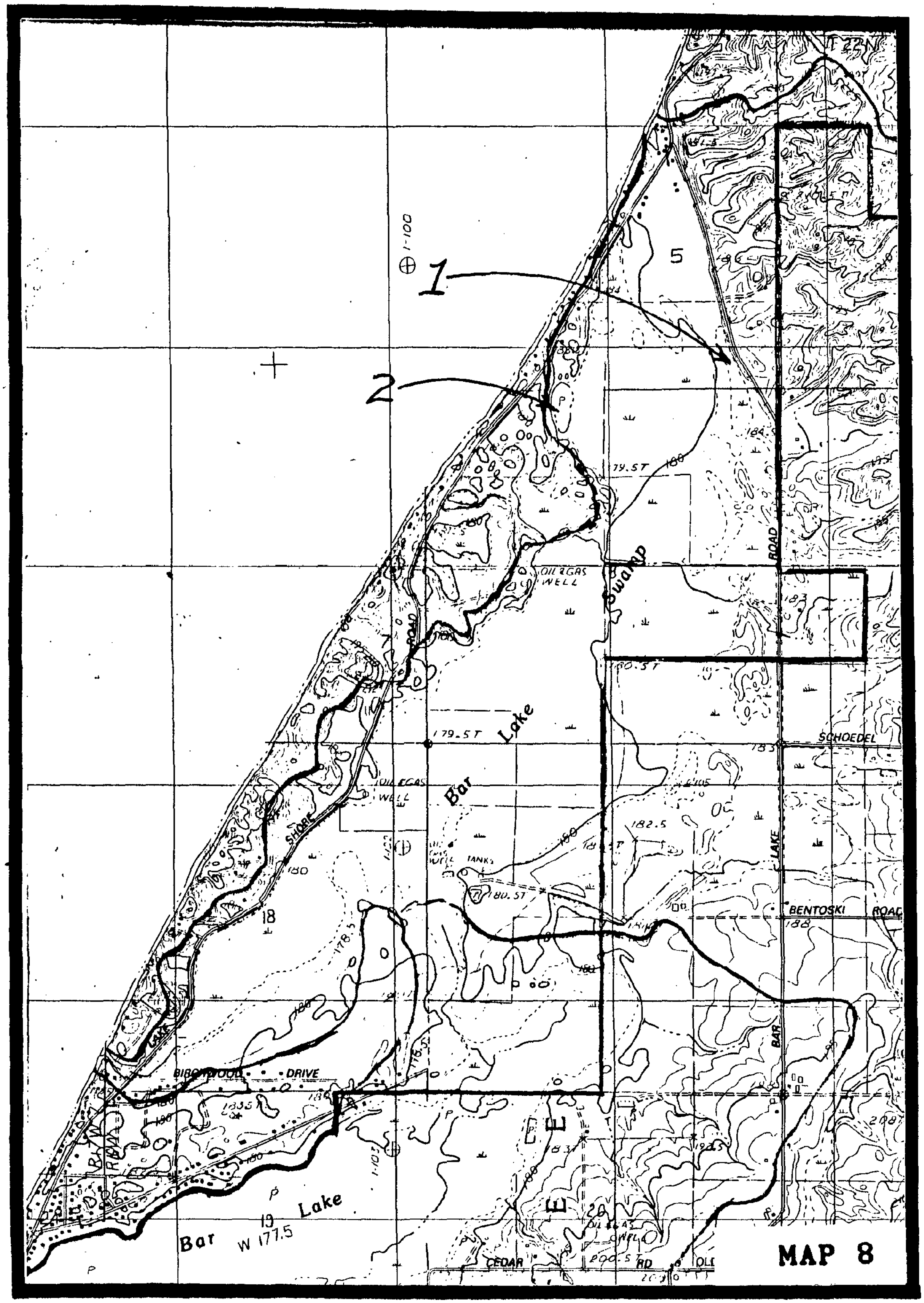
MAP 5



MAP 6
1
2
3
COOPER CREEK
Cooper
ROAD
LOOKOUT
STAIRS
LOOKOUT
Porter Creek
LAKE MICHIGAN
RECREATION AREA
FOREST
G R A N T
MANISTEE NATIONAL
ROAD
GREEN
Nordhouse Lake
NURNBERG
ROAD
FOREST
BDY
R18W
R17W
23
24
25
26
35
36



MAP 7
1
2
3
4
T21N
T20N
MANISTEE CO
MASON CO
Magoon
Creek
Gurney
Creek
SASS ROAD
JEPSON ROAD
MORTON
PHYLLIS
ROAD
FILER
TRAIL ROAD
SALT WELL
NATIONAL FOREST


1
2
5
18
19
ROAD
SHORE
LAKE
Swamp
Bar Lake
OIL & GAS WELL
TANKS
SCHOEDEL
BENTOSKI ROAD
BAR LAKE ROAD
BIRCHWOOD DRIVE
CEDAR RD
Bar Lake
W 177.5

MAP 8

Photo 1. View to the west across a dune-pocketed wetland area immediately landward of a barrier dune in the Fruitvale Dunes system. The dune appears as higher topography at the horizon of the photo. Trees in the foreground are on a low ridge along the east side of the shrub carr/marsh area appearing in the midground of the photo.

Photo 2. View from the barrier dune to the northeast across the lower end of a dune-pocketed wetland area in the Fruitvale Dunes System. This area is at the southern end of the elongated landward dune-pocketed wetland shown in the previous photograph.

Photo 3. View to the southeast across a dune-pocketed wetland area in the Fruitvale Dune System. This shrub carr/marsh area is separated from the wetlands at the foot of the barrier dune by a low ridge, possibly of dune or shoreline origin (see foreground of Photo 1). Otherwise it is very similar to and essentially continuous with the dune-pocketed wetland shown in the previous two photographs.

Photo 4. View to the west from a dune ridge looking down on a small dune-pocketed wetland in the Fruitvale Dune System. This wetland area is undergoing succession from shrub carr vegetation dominated by Salix discolor and Salix lucida to tree cover -- Pinus strubus, Fraxinus pensylvanica, Acer rubrum, and Betula papyrifera.

A

B

Photo 5. The Horseshoe Lake wetland area in the Fruitvale Dune System. A -- View across the ombrotrophic northern end of the wetland; B -- View to the north across the lower, more minerotrophic part of the wetland.

A

B

Photo 6. Wetland areas located upgradient from the primary catchment in the Fruitvale North dune-pocketed wetlands watershed.

Photo 7. Winston Road wetland. This area is located close to the shoreline but drains inland.

Photo 8. View of Long Lake basin looking eastward from dune blocking lower end.

Photo 9. Skinny Lake dune-pocketed wetland (Type A).

Photo 10. Wetland area at the northeast end of Bigsbie Lake.

Photo 11. Little Silver Lake and surrounding wetlands.

Photo 12. Bog lake and surrounding leatherleaf and wetland area at Cedar Point Park Road.

Photo 13. Ridge Road wetland area (not dune-pocketed).

A

B

Photo 14. Spartina marsh catchment area in the Nordhouse Dunes System.

Photo 15. Cooper Creek interdunal peat area.

A

B

Photo 16. Manistee/Mason county line wetland area.

A

B

Photo 17. Catchment area of Manistee/Mason county line dune-pocketed wetland watershed.

Photo 18. Cedar swamp with patchy openings along the east side of Bar Lake Swamp.

Photo 19. Willow shrub carr (background) and sedge (foreground) vegetation in locally pocketed areas along the base of the dunes in Bar Lake Swamp.

APPENDIX II.

A. Listing of watersheds and drainage areas along the eastern Lake Michigan shoreline by type.

B. Listing and topographic map copies of dune-pocketed wetlands watersheds along the eastern Lake Michigan shoreline (original watershed maps are provided in sheet form, suitable for digitizing).

Table A2-1. Listing of watersheds and drainage areas associated with the eastern Lake Michigan shoreline. Series numbered LM001 through LM157 (from the Indiana/Michigan state line north to Portage Lake in Benzie County) includes all watersheds and drainage areas in the following types:

- UIS - Unimpeded Inland Stream Watershed
- USS - Unimpeded Shoreline Stream Watershed
- DRM - Drowned River Mouth Watershed [Inland Impeded Stream Watershed]
- SIS - Somewhat Dune-Impeded Shoreline Stream Watershed
- ISC - Intermittent Stream Channel Watershed
- DPW - Dune-Pocketed Wetlands Watershed
- BMB - Bay Mouth Bar Lake Watershed

- DDD - Dunal Direct Drain Areas [includes inter-dunal drainage areas (not mapped)]
- ODD - Other Direct Drain Areas [includes glacial kettle areas, etc.]

Direct drain areas (DDD and ODD) are not included in the LM801 through LM844 series (North of Portage Lake).

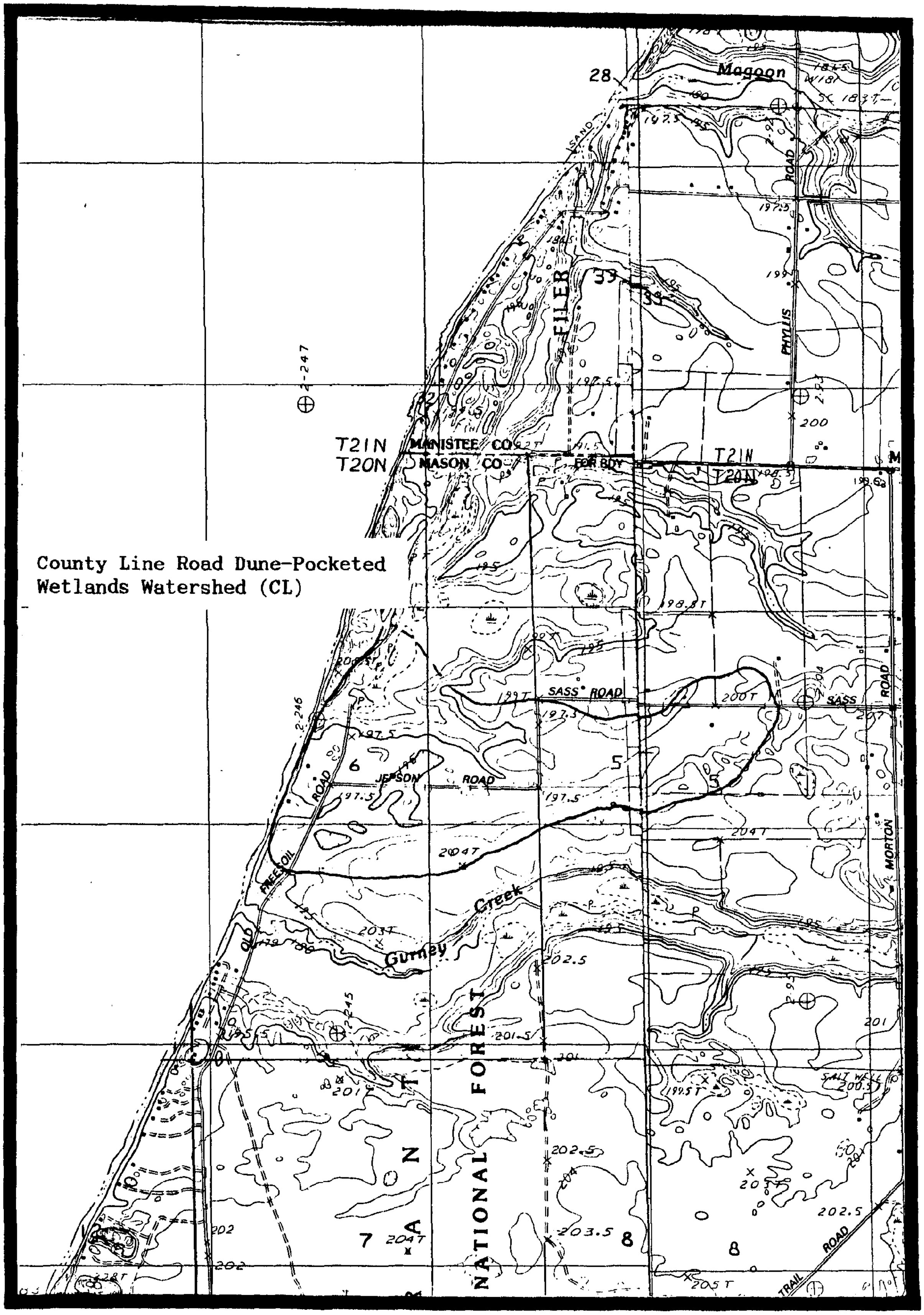
#	Name	Type Code	County	Quadrangle Sheet
LM001	Michiana Drainage Area	DDD	BERRIEN	NEW BUFFALO WEST
LM002	White Ditch Watershed	USS	BERRIEN	NEW BUFFALO WEST
LM003	Grand Beach Drainage Area	DDD	BERRIEN	NEW BUFFALO WEST
LM004	New Buffalo Lake Watershed	SIS	BERRIEN	NEW BUFFALO WEST
LM005	Galien River Watershed	DRM	BERRIEN	NEW BUFFALO EAST
LM006	Lakeview Drainage Area	ODD	BERRIEN	NEW BUFFALO EAST
LM007	Lakeside Creek Watershed	USS	BERRIEN	NEW BUFFALO EAST
LM008	North Lakeside Creek Watershed	USS	BERRIEN	NEW BUFFALO EAST
LM009	Turner Shores Drainage Area	ODD	BERRIEN	NEW BUFFALO EAST
LM010	North Turner Shores Creek Watershed	USS	BERRIEN	NEW BUFFALO EAST
LM011	Youngren Road Watershed	ODD	BERRIEN	NEW BUFFALO EAST/BRIDGEMAN
LM012	Harbert Shores Drainage Area	DDD	BERRIEN	NEW BUFFALO EAST/BRIDGEMAN
LM013	Hazelhurst Creek Watershed	USS	BERRIEN	BRIDGEMAN
LM014	Bethany Beach Drainage Area	DDD	BERRIEN	BRIDGEMAN
LM015	Chickaming Creek Watershed	USS	BERRIEN	BRIDGEMAN
LM016	Tower Hill Shorelands Drainage Area	DDD	BERRIEN	BRIDGEMAN
LM017	Painterville Drain Watershed	USS	BERRIEN	BRIDGEMAN
LM018	Warren Dune State Park Drainage Area	DDD	BERRIEN	BRIDGEMAN
LM019	Warren Dune-Pocketed Wetlands Watershed	DPW	BERRIEN	BRIDGEMAN
LM020	Bridgeman Creek Watershed	USS	BERRIEN	BRIDGEMAN
LM021A	Warren Dunes North Drainage Area	DDD	BERRIEN	BRIDGEMAN/STEVENSVILLE
LM021B	Warren Dunes North Interdunal Wetland Drainage Area	DDD	BERRIEN	BRIDGEMAN
LM022	Thornton Valley Dune-Pocketed Wetlands Watershed #1	DPW/ART	BERRIEN	BRIDGEMAN
LM023	Thornton Valley Dune-Pocketed Wetlands Watershed #2	DPW/ART	BERRIEN	BRIDGEMAN
LM024	Grand Mere Bar Drainage Area	DDD	BERRIEN	BRIDGEMAN
LM025	Grand Mere Lakes Drainage Area	BMB	BERRIEN	BRIDGEMAN/STEVENSVILLE
LM026	Section 16 Drainage Area	ODD	BERRIEN	STEVENSVILLE
LM027	Shoreham Drainage Area	ODD	BERRIEN	STEVENSVILLE/BENTON HARBOR
LM028	St. Joseph River Watershed	DRM	BERRIEN	BENTON HARBOR/BENTON HEIGHTS
LM029	Higman Park Drainage Area	ODD	BERRIEN	BENTON HARBOR/BENTON HEIGHTS
LM030	Bundy Creek Watershed	USS	BERRIEN	BENTON HEIGHTS/COLOMA
LM031	Lake Michigan Beach Creek Watershed	USS	BERRIEN	BENTON HEIGHTS/COLOMA
LM032A	South Blue Star Dunes Drainage Area	DDD	BERRIEN/VAN BUREN	COLOMA/COVERT
LM033	Harris Lake Basin	ODD/GLB	BERRIEN	COLOMA
LM034	Hibbard Lake Basin	ODD/GLB	BERRIEN	COLOMA
LM035	Jacobs Chapel Lake Basin	ODD/GLB	BERRIEN	COLOMA
*LM036	Berrien-Van Buren Lake Basin	ODD/GLB	BERRIEN/VAN BUREN	COLOMA
LM037	Rogers Creek Watershed	USS	BERRIEN/VAN BUREN	COLOMA/COVERT
LM038	Linden Hills Drainage Area	DDD	VAN BUREN	COVERT
LM039	Mud Lake Dune-Pocketed Wetlands Watershed	DPW/ART	BERRIEN/VAN BUREN	COLOMA/COVERT
LM040	Fish Cemetery Dune-Pocketed Wetlands Watershed	DPW/ART	VAN BUREN	COVERT
LM041	Brandywine Creek Watershed	SIS	VAN BUREN	COVERT
LM042	Van Buren State Park Drainage Area	DDD	VAN BUREN	COVERT
LM043	Dyckman Swamp Pocketed Wetlands Watershed	DPW/ART	VAN BUREN	COVERT
LM044	Ruggles Creek Watershed	USS	VAN BUREN	COVERT
LM045	Blue Star Creek Watershed	USS	VAN BUREN	COVERT
LM046	Deerlick Creek Watershed	USS	VAN BUREN	COVERT/SOUTH HAVEN
LM047	11th Avenue Drainage Area	ODD	VAN BUREN	SOUTH HAVEN
LM048	Armory Creek Watershed	UIS	VAN BUREN	SOUTH HAVEN
LM049	South Haven Township Drainage Area	ODD	VAN BUREN	SOUTH HAVEN
LM050	Black River Watershed	UIS	VAN BUREN	SOUTH HAVEN +
LM051	North Shore Drainage Area	ODD	VAN BUREN/ALLEGAN	SOUTH HAVEN
LM052	North Shore Drive Creek Watershed	USS	ALLEGAN	SOUTH HAVEN
LM053	Mt. Pleasant Drainage Area	ODD	ALLEGAN	SOUTH HAVEN/LACOTA/GLENN
LM054	Creekwood Watershed	USS	ALLEGAN	LACOTA/GLENN
LM055	Glenn Creek Watershed	USS	ALLEGAN	GLENN
LM056	71st Street Drainage Area	ODD	ALLEGAN	GLENN
LM057	Section 19 Creek Watershed	USS	ALLEGAN	GLENN
LM058	118th Street Drainage Area	ODD	ALLEGAN	GLENN
LM059	Orchard Creek Watershed	USS	ALLEGAN	GLENN
LM060	Section 18 Drainage Area	ODD	ALLEGAN	GLENN
LM061	Plummerville Creek Watershed	USS	ALLEGAN	GLENN
LM062	County Park Creek Watershed	USS	ALLEGAN	GLENN
LM063	West Side County Park Drainage Area	ODD	ALLEGAN	GLENN
LM064	Pier Cove Creek Watershed	USS	ALLEGAN	GLENN
LM065	Townline Shores Drainage Area	ODD	ALLEGAN	GLENN
LM066	Ramps Creek Watershed	USS	ALLEGAN	GLENN

LM067 Johnson Marher Creek Watershed	USS	ALLEGAN	GLENN
LM068 Two Ponds Creek Watershed	USS	ALLEGAN	GLENN
LM069 Bench Marh 633 Drainage Area	ODD	ALLEGAN	GLENN
LM070 Trailer Park Creek Watershed	USS	ALLEGAN	GLENN
LM071A Douglas Beach Drainage Area	ODD	ALLEGAN	GLENN/SAUGATUCK
LM071B Mt. Baldhead Dunes Drainage Area	DDD	ALLEGAN	SAUGATUCK
LM072 Kalamazoo River Watershed	DRM	ALLEGAN	SAUGATUCK +
LM073 Pelican Peak Drainage Area	DDD	ALLEGAN	SAUGATUCK
LM074 Saugatuck Dune-Pocketed Wetlands Watershed	DPW	ALLEGAN	SAUGATUCK
LM075 Halfway Creek Watershed	SIS	ALLEGAN/OTTAWA	SAUGATUCK/HOLLAND WEST
LM076 Gilligan Lake Dune-Pocketed Wetlands Watershed	DPW	ALLEGAN	SAUGATUCK
LM077 Castle Park Dune Drainage Area	DDD	OTTAWA	SAUGATUCK/HOLLAND WEST
LM078A Lake Macatawa Watershed	DRM	ALLEGAN	SAUGATUCK/HOLLAND WEST
LM078B Kelly Lake Dune-Pocketed Wetlands Watershed	DPW/ART	OTTAWA	HOLLAND WEST +
LM079A Holland State Park Drainage Area	DDD	OTTAWA	HOLLAND WEST
LM079B West Ottawa Drainage Area	ODD	OTTAWA	HOLLAND WEST/PORT SHELDON
LM080 Cooling Water Drain (CPCO) Area	ODD/ART	OTTAWA	PORT SHELDON
LM080A Pigeon River Watershed	DRM	OTTAWA	PORT SHELDON +
LM080B Ten Hagen Creek (Sloan Pond) Watershed	SIS	OTTAWA	HOLLAND WEST/PORT SHELDON
LM081 Campbell - Mt. Baldy Dunes Drainage Area	DDD	OTTAWA	PORT SHELDON
LM082 Hiawatha Low Dunes Drainage Area	DDD	OTTAWA	PORT SHELDON
LM083 Little Pigeon Creek Watershed	SIS	OTTAWA	PORT SHELDON
LM084A Pine Ridge Drainage Area	ODD	OTTAWA	PORT SHELDON/GRAND HAVEN
LM084B Ottawa County Dunes Drainage Area	DDD	OTTAWA	PORT SHELDON/GRAND HAVEN
LM085 Grand River Watershed	DRM	OTTAWA	GRAND HAVEN
LM086 Hoffmaster State Park Dunes Drainage Area	DDD	OTTAWA/MUSKEGON	GRAND HAVEN/MUSKEGON WEST
LM087 Little Black Creek Watershed	USS/ART	OTTAWA/MUSKEGON	GRAND HAVEN/MUSKEGON WEST+
LM088 Norton Dunes Drainage Area	DDD	MUSKEGON	MUSKEGON WEST
LM089 Mona Lake (Black Creek) Watershed	DRM	MUSKEGON	MUSKEGON WEST
LM090 Laketon Township Dunes Drainage Area	DDD	MUSKEGON	MUSKEGON WEST
LM091 Muskegon River Watershed	DRM	MUSKEGON	MUSKEGON WEST/DALTON
LM092A Muskegon State Park Dunes Drainage Area	DDD	MUSKEGON	MUSKEGON WEST/DALTON
LM092B Pioneer Park Drainage Area	ODD	MUSKEGON	DALTON
LM093 Pioneer Park Creek Watershed	USS	MUSKEGON	DALTON
LM094A Laketon Dunes Drainage Area	ODD	MUSKEGON	DALTON/MICHILINDA
LM094B Duck Lake Dunes Drainage Area	DDD	MUSKEGON	MICHILINDA
LM095 Muskrat Lake Dune-Pocketed Wetlands Watershed	DPW	MUSKEGON	DALTON/MICHILINDA
LM096 Duck Lake Watershed	DRM	MUSKEGON	DALTON/MICHILINDA
LM097A Michilinda Drainage Area	ODD	MUSKEGON	MICHILINDA
LM097B Michilinda Dunes Drainage Area	DDD	MUSKEGON	MICHILINDA
LM098 White Lake Watershed	DRM	MUSKEGON	MICHILINDA/FLOWER CREEK
LM098B Pierson Drain Watershed	SIS	MUSKEGON	FLOWER CREEK
LM099 Old Channel Trail Drainage Area	DDD	MUSKEGON	FLOWER CREEK
LM100 Lehman Road Intermitent Dendritic Drainage Area	ISC	MUSKEGON	FLOWER CREEK
LM101 Fruitvale Creek Watershed	USS	MUSKEGON	FLOWER CREEK
LM102 Fruitvale Dunes Drainage Area	DDD	MUSKEGON	FLOWER CREEK
LM103 Fruitvale South Dune-Pocketed Wetlands Watershed	DPW	MUSKEGON	FLOWER CREEK
LM104 Fruitvale North Dune-Pocketed Wetlands Watershed	DPW	MUSKEGON	FLOWER CREEK
LM105 Little Flower Creek Watershed	SIS	MUSKEGON	FLOWER CREEK
LM106 Flower Creek Dunes Drainage Area	DDD	MUSKEGON	FLOWER CREEK
LM107 Flower Creek Watershed	DRM	MUSKEGON	FLOWER CREEK
LM108 Claybanks Township Shoreline Drainage Area	ODD	MUSKEGON/OCEANA	FLOWER CREEK/TOWN CORNERS
LM109 Township Park Creek Watershed	USS	OCEANA	TOWN CORNERS
LM110 South Whiskey Creek Drainage Area	ODD	OCEANA	TOWN CORNERS
LM111 Whiskey Creek Watershed	USS	OCEANA	TOWN CORNERS
LM112 Benona Township South Dunes Drainage Area	DDD	OCEANA	TOWN CORNERS/BIGSBEE LAKE
LM113 Long Lake Dune-Pocketed Wetlands Watershed	DPW	OCEANA	TOWN CORNERS
LM114 Skinny Lake Dune-Pocketed Wetlands Watershed	DPW	OCEANA	TOWN CORNERS
LM115 Stony Lake Watershed	DRM	OCEANA	TOWN CORNERS/BIGSBEE LAKE
LM116A Cobmoosa Shores Dunes Drainage Area	DDD	OCEANA	BIGSBEE LAKE
LM116B East-of-Comoosa Drainage Area	ODD	OCEANA	BIGSBEE LAKE
LM116C South Little Sable Drainage Area	ODD	OCEANA	BIGSBEE LAKE/LITTLE SABLE PT
LM116D Little Point Sable Dunes Drainage Area	DDD	OCEANA	LITTLE SABLE POINT
LM117 Bigsbie Lake Dune-Pocketed Wetlands Watershed	DPW	OCEANA	BIGSBEE LAKE/LITTLE SABLE PT
LM118 Silver Creek (Lake) Watershed	BMB	OCEANA	LITTLE SABLE POINT/MEARS
LM119A Silver Lake State Park Drainage Area	DDD	OCEANA	LITTLE SABLE POINT/MEARS
LM119B Richmonds Inlet Shoreline Drainage Area	ODD	OCEANA	MEARS
LM119C Behind-the-Bluffs Drainage Area	ODD	OCEANA	MEARS
LM119D Ridge Road Drainage Area	ODD	OCEANA	MEARS/PENTWATER
LM119E Pentwater Dunes Drainage Area	DDD	OCEANA	PENTWATER
LM120 Pentwater Lake Watershed	DRM	OCEANA	PENTWATER
LM121 Pentwater North Dunes Drainage Area	DDD	OCEANA/MASON	PENTWATER
LM122 Bass Lake Watershed	BMB/USS	OCEANA/MASON	PENTWATER
LM123 Summit Township Dunes Drainage Area	DDD	MASON	PENTWATER
LM124 Section 23 Creek Watershed	USS	MASON	PENTWATER
LM125 Section 23 Shoreline Drainage Area	ODD	MASON	PENTWATER
LM126 Meisenheimer Road Creek Watershed	USS	MASON	PENTWATER
LM127 South Reservoir Lakeshore Drainage Area	ODD	MASON	PENTWATER/LUDINGTON
LM128 Section 15 Creek Watershed	USS	MASON	PENTWATER/LUDINGTON
LM129 Radio Tower Drainage Area	ODD	MASON	LUDINGTON
LM130 Ludington Hydroelectric Plant Outlet	ART	MASON	LUDINGTON
LM131 White Pine Village Dunes Drainage Area	DDD	MASON	LUDINGTON
LM132 Pere Marquette River Watershed	DRM	MASON	LUDINGTON
LM133A Ludington Shoreline Drainage Area	ODD	MASON	LUDINGTON
LM133B North Epworth Dunes Drainage Area	DDD	MASON	LUDINGTON
LM134 Lincoln River Watershed	DRM	MASON	LUDINGTON
LM135 Ludington Dunes State Park Drainage Area	DDD	MASON	HAMLIN LAKE
LM136 Big Sable (Hamlin Lake) Watershed	BMB/DRM	MASON	HAMLIN LAKE
LM137A Big Sable Point Dunes Drainage Area	DDD	MASON	HAMLIN LAKE

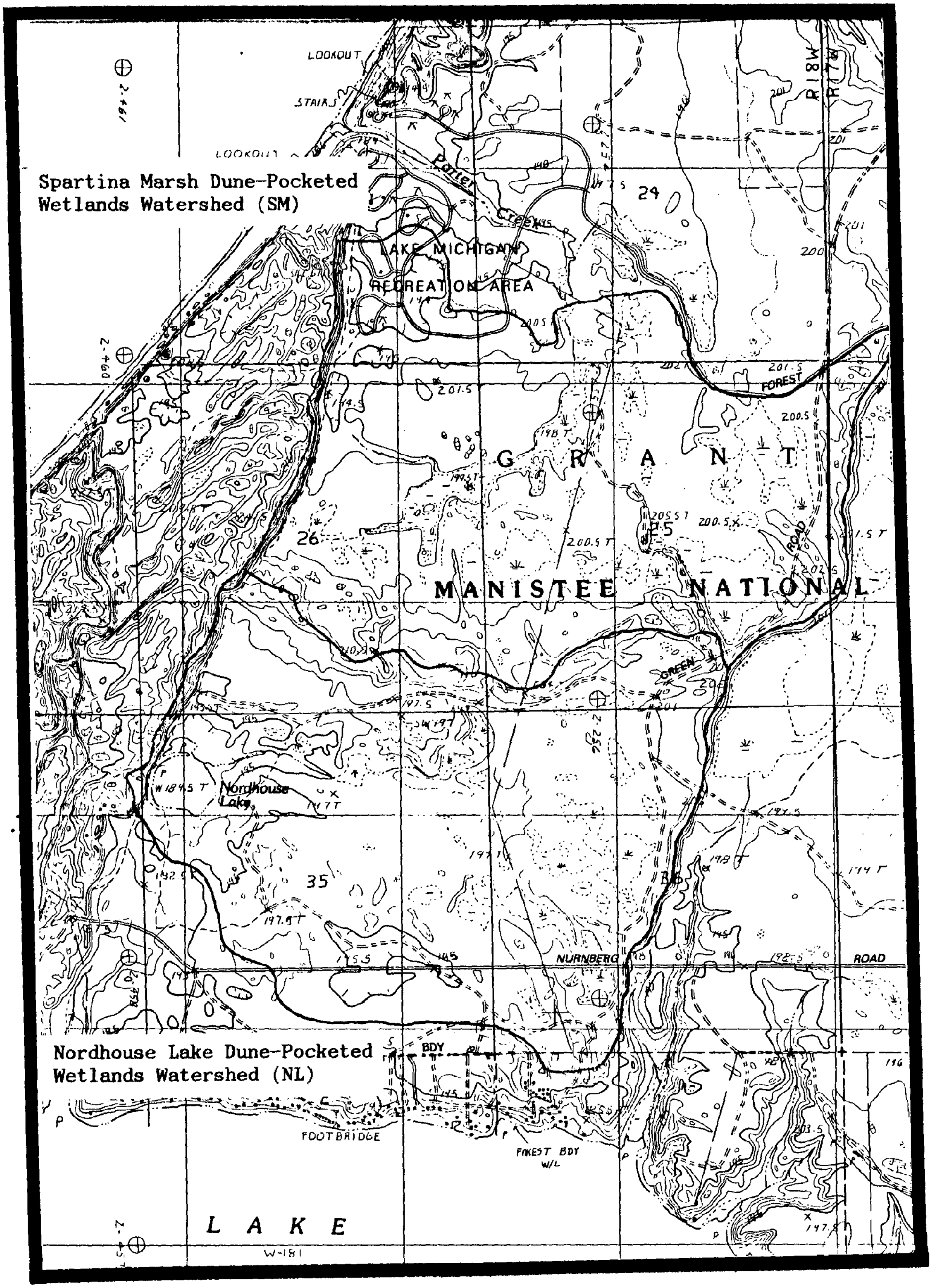
LM137B	Nordhouse Dunes Drainage Area	DDD	MASON	HAMLIN LAKE
LM138	Nordhouse Lake Dune-Pocketed Wetlands Watershed	DPW	MASON	HAMLIN LAKE
LM139	Spartina Marsh Dune-Pocketed Wetlands Watershed	DPW	MASON	HAMLIN LAKE
LM140A	Porter Creek Watershed	USS	MASON	LUDINGTON/MANISTEE
LM140B	Cooper Creek Road Interdunal Peatland Area	DDD/INT	MASON	MANISTEE
LM141	Northern Outlier Drainage Area	DDD	MASON	LUDINGTON/MANISTEE
LM142	Cooper Creek Watershed	USS	MASON	LUDINGTON/MANISTEE
LM143A	Old Freesoil Road Drainage Area	DDD	MASON	MANISTEE
LM143B	Old Freesoil Road Flats Drainage Area	ODD	MASON	MANISTEE
LM144	Gurney Creek Watershed	USS	MASON	MANISTEE
LM145	County Line Road South Low Dune Drainage Area	UIS	MASON/MANISTEE	MANISTEE
LM146	County Line Road Dune-Pocketed Wetlands Watershed	DPW	MASON/MANISTEE	MANISTEE
LM147	Section 33 Creek Watershed	SIS	MANISTEE	MANISTEE
LM148	Magoon Creek Watershed	USS	MANISTEE	MANISTEE
LM149	Red Apple Road Drainage Area	ODD	MANISTEE	MANISTEE
LM150	Golf Coarse Creek Watershed	USS	MANISTEE	MANISTEE
LM151	Section 10 Shoreline Drainage Area	DDD	MANISTEE	MANISTEE
LM152	Manistee River Watershed	DRM	MANISTEE	MANISTEE/PARKDALE
LM153	Orchard Beach State Park Drainage Area	ODD	MANISTEE	PARKDALE
LM154A	Bar Lake Watershed	BMB	MANISTEE	PARKDALE
LM154B	South Bar Lake Swamp Watershed	BMB	MANISTEE	PARKDALE
LM154C	North Bar Lake Outlet Watershed	BMB	MANISTEE	PARKDALE
LM155	Bar Lake Village Drainage Area	ODD	MANISTEE	PARKDALE
LM156	Bar Lake Shoreline Dunes Drainage Area	DDD	MANISTEE	PARKDALE
LM157	Williamsport Dunes Drainage Area	DDD	MANISTEE	PARKDALE
LM158	Portage Lake Watershed	BMB	MANISTEE	PARKDALE
LM801	Arcadia Lake	BMB	MANISTEE	ONEKEMA
LM802	Upper and Lower Herring Lake	BMB	BENZIE	ELBERTA
LM803	Betsie River	DRM	BENZIE	ELBERTA/FRANKFURT
LM804	Crystal Lake	BMB	BENZIE	FRANKFURT/BEULAH
LM805	Platte River	UIS	BENZIE	FRANKFURT/BEULAH
LM806	Otter Creek	USS	BENZIE	EMPIRE
LM807	North and South Bar Lakes	BMB	LEELANAU	EMPIRE
LM808	Crystal Run	USS	LEELANAU	EMPIRE
LM809	Good Harbor Creek	USS	LEELANAU	GOOD HARBOR BAY
LM810	Kovorick Creek	USS	LEELANAU	GILLS PIER
LM811	Gills Creek	USS	LEELANAU	GILLS PIER
LM812	Roaring Brook	ISC	LEELANAU	GILLS PIER
LM813	Onomonee Dry Gulch	ISC	LEELANAU	GILLS PIER
LM814	Onominee Dry Gulch	ISC	LEELANAU	GILLS PIER
LM815	Christmas Cove Creek	ISC	LEELANAU	NORTHPORT NW
LM816	Mud Lake Creek	USS	LEELANAU	NORTHPORT
LM817	Creswell Creek	USS	ANTRIM	CENTRAL LAKE
LM818	Golden Beach Creek	USS	ANTRIM	CENTRAL LAKE
LM819	Section 35 Creek	USS	ANTRIM	CENTRAL LAKE
LM820	Guyer Creek	USS	ANTRIM	ATWOOD
LM821	West Guyer Creek	USS	ANTRIM	ATWOOD
LM822	Antrim Creek	USS	ANTRIM	ATWOOD
LM823	County Line Creek	USS	CHARLEVOIX/ANTRIM	ATWOOD
LM824	Whiskey Creek	USS	CHARLEVOIX	ATWOOD
LM825	Inwood Creek	UIS	CHARLEVOIX	CHARLEVOIX
LM826	McGreen Creek	UIS	CHARLEVOIX	CHARLEVOIX
LM827	Pine River (Lake Charlevoix)	USS	CHARLEVOIX	CHARLEVOIX
LM828	Range Line Creek	USS	CHARLEVOIX	IRONTON
LM829	Susan Creek	UIS	CHARLEVOIX	IRONTON
LM830	5 Mile Creek	USS	EMMET	FOREST BEACH
LM831	Forest Beach 1, 2, and 3	ISC	EMMET	FOREST BEACH
LM832	West Traverse Township Creek	USS	EMMET	FOREST BEACH
LM833	Friendship Creek	USS	EMMET	FOREST BEACH
LM834	Ryan's Corner Dry Gulch	ISC	EMMET	GOOD HART
LM835	Horseshoe Bend	USS	EMMET	GOOD HART
LM836	Devil's Elbow Creek	ISC	EMMET	GOOD HART
LM837	Good Hart Dry Gulches 1-6	ISC	EMMET	GOOD HART
LM838	Beckons Corners Creek	USS	EMMET	GOOD HART
LM839	Cross Village Campground Creek	USS	EMMET	CROSS VILLAGE
LM840	Wycamp Creek (Wycamp Lake)	UIS	EMMET	CROSS VILLAGE
LM841	Billiau Hill Dune-Pocketed Wetland Area	DPW	EMMET	BLISS
LM842	Big Sucker Creek	USS	EMMET	BLISS
LM843	Little Sucker Creek	USS	EMMET	BLISS
LM844	Big Stone Creek	USS	EMMET	BLISS

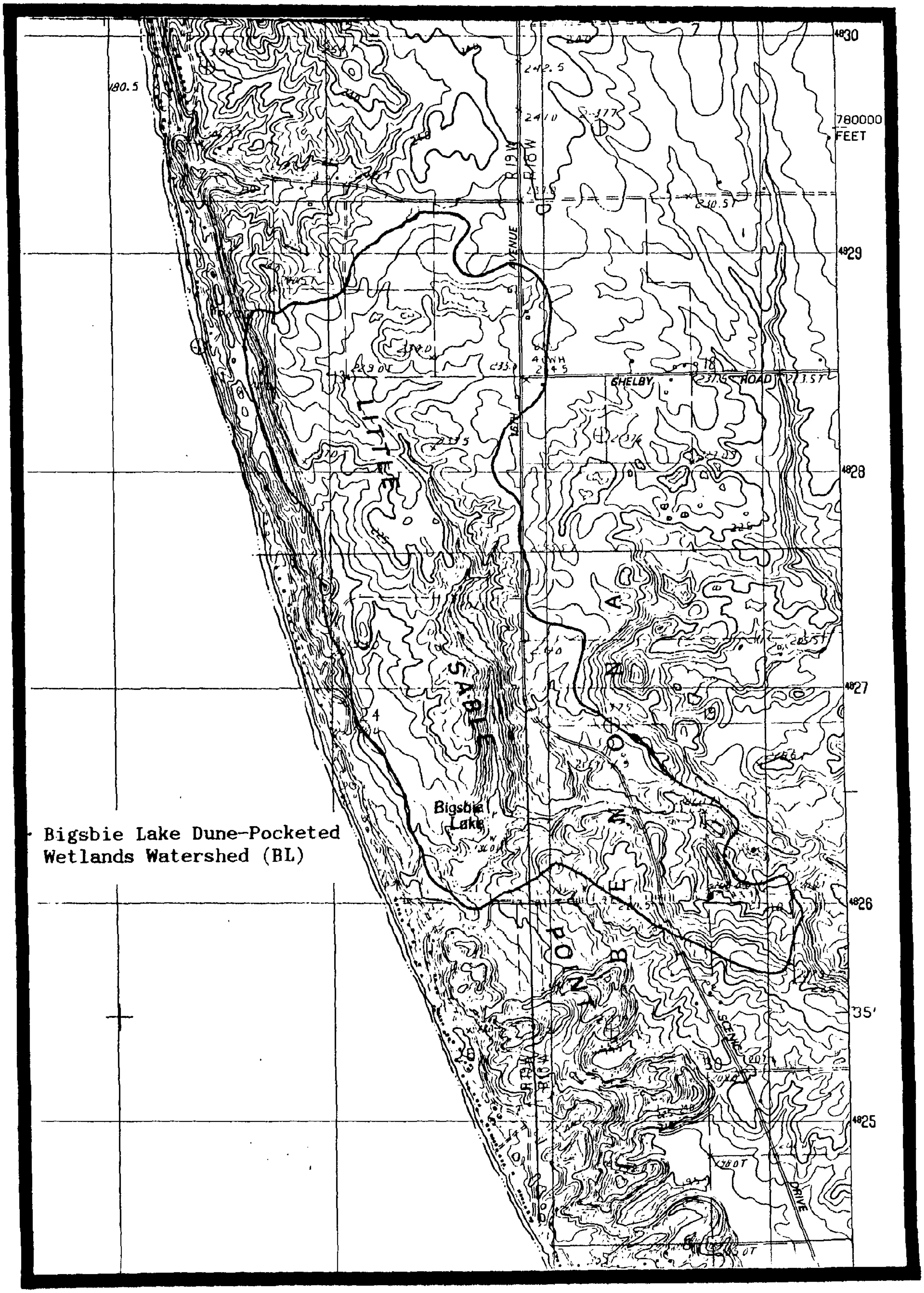
Table A2-2. Dune-pocketed wetlands watersheds of the eastern Lake Michigan shoreline (listed south to north).

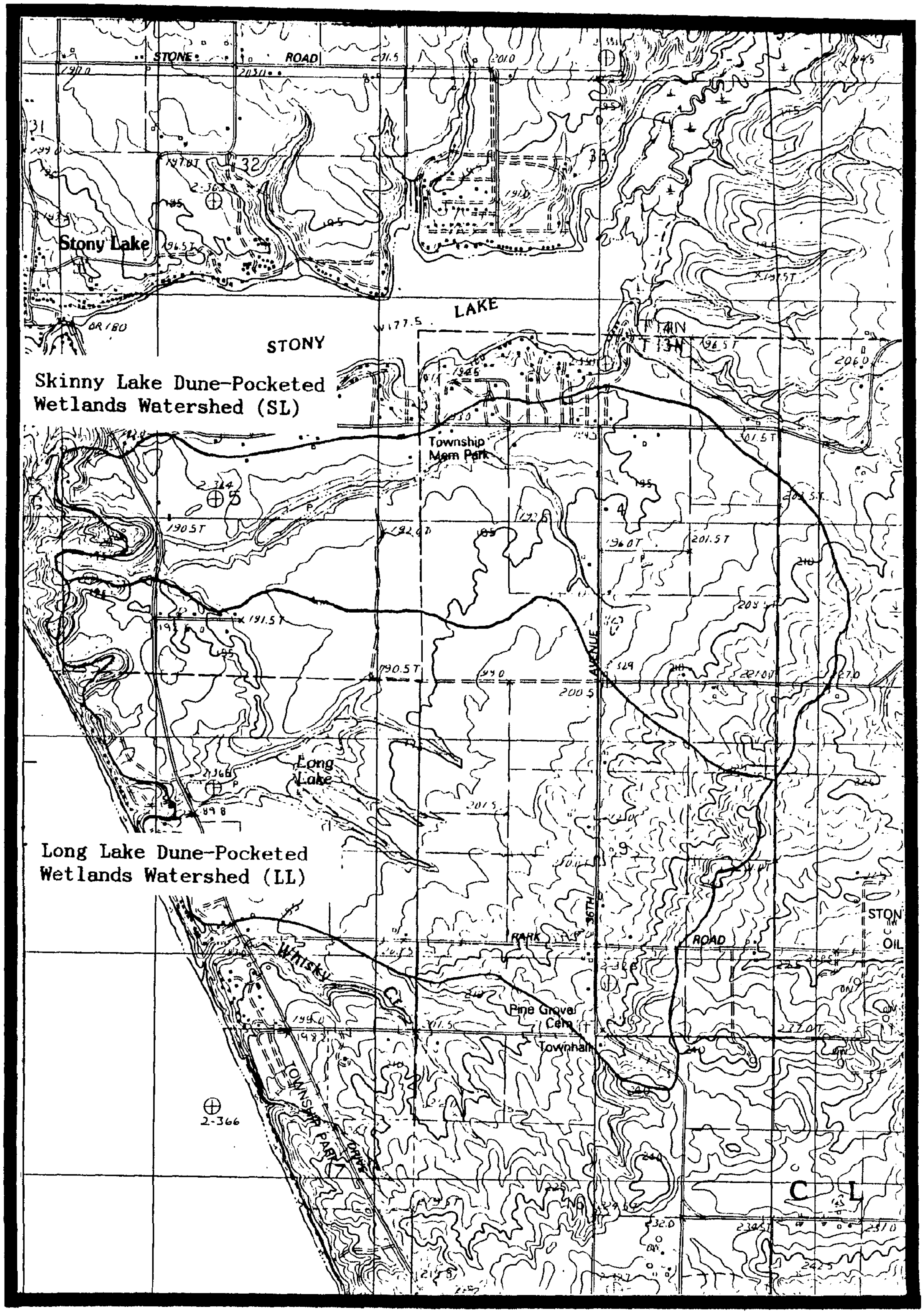
Number	Name/Code	County	Quadrangle Sheet
LM019	Warren Dune-Pocketed Wetlands Watershed (WD)	BERRIEN	BRIDGEMAN
LM022	Thornton Valley Dune-Pocketed Wetlands Watershed #1 (TV1)	BERRIEN	BRIDGEMAN
LM023	Thornton Valley Dune-Pocketed Wetlands Watershed #2 (TV2)	BERRIEN	BRIDGEMAN
LM039	Mud Lake Dune-Pocketed Wetlands Watershed (ML)	BERRIEN+	COLOMA/COVERT
LM040	Fish Cemetery Dune-Pocketed Wetlands Watershed (FC)	VAN BUREN	COVERT
LM043	Dyckman Swamp Pocketed Wetlands Watershed (DS)	VAN BUREN	COVERT
LM074	Sangutuck Dune-Pocketed Wetlands Watershed (SD)	ALLEGAN	SAUGATUCK
LM076	Gilligan Lake Dune-Pocketed Wetlands Watershed (GL)	ALLEGAN	SAUGATUCK
LM078B	Kelly Lake Dune-Pocketed Wetlands Watershed (KL)	OTTAWA	HOLLAND WEST+
LM095	Muskrat Lake Dune-Pocketed Wetlands Watershed (MS)	MUSKEGON	DALTON/MICHILINDA
LM103	Fruitvale South Dune-Pocketed Wetlands Watershed (FS)	MUSKEGON	FLOWER CREEK
LM104	Fruitvale North Dune-Pocketed Wetlands Watershed (FN)	MUSKEGON	FLOWER CREEK
LM113	Long Lake Dune-Pocketed Wetlands Watershed (LL)	OCEANA	TOWN CORNERS
LM114	Skinny Lake Dune-Pocketed Wetlands Watershed (SL)	OCEANA	TOWN CORNERS
LM117	Bigsbie Lake Dune-Pocketed Wetlands Watershed (BL)	OCEANA	BIGSBEE LAKE+
LM138	Nordhouse Lake Dune-Pocketed Wetlands Watershed (NL)	MASON	HAMLIN LAKE
LM139	Spartina Marsh Dune-Pocketed Wetlands Watershed (SM)	MASON	HAMLIN LAKE
LM146	County Line Road Dune-Pocketed Wetlands Watershed (CL)	MASON+	MANISTEE
LM841	Billiau Hill Dune-Pocketed Wetland Area (BH)	EMMET	BLISS

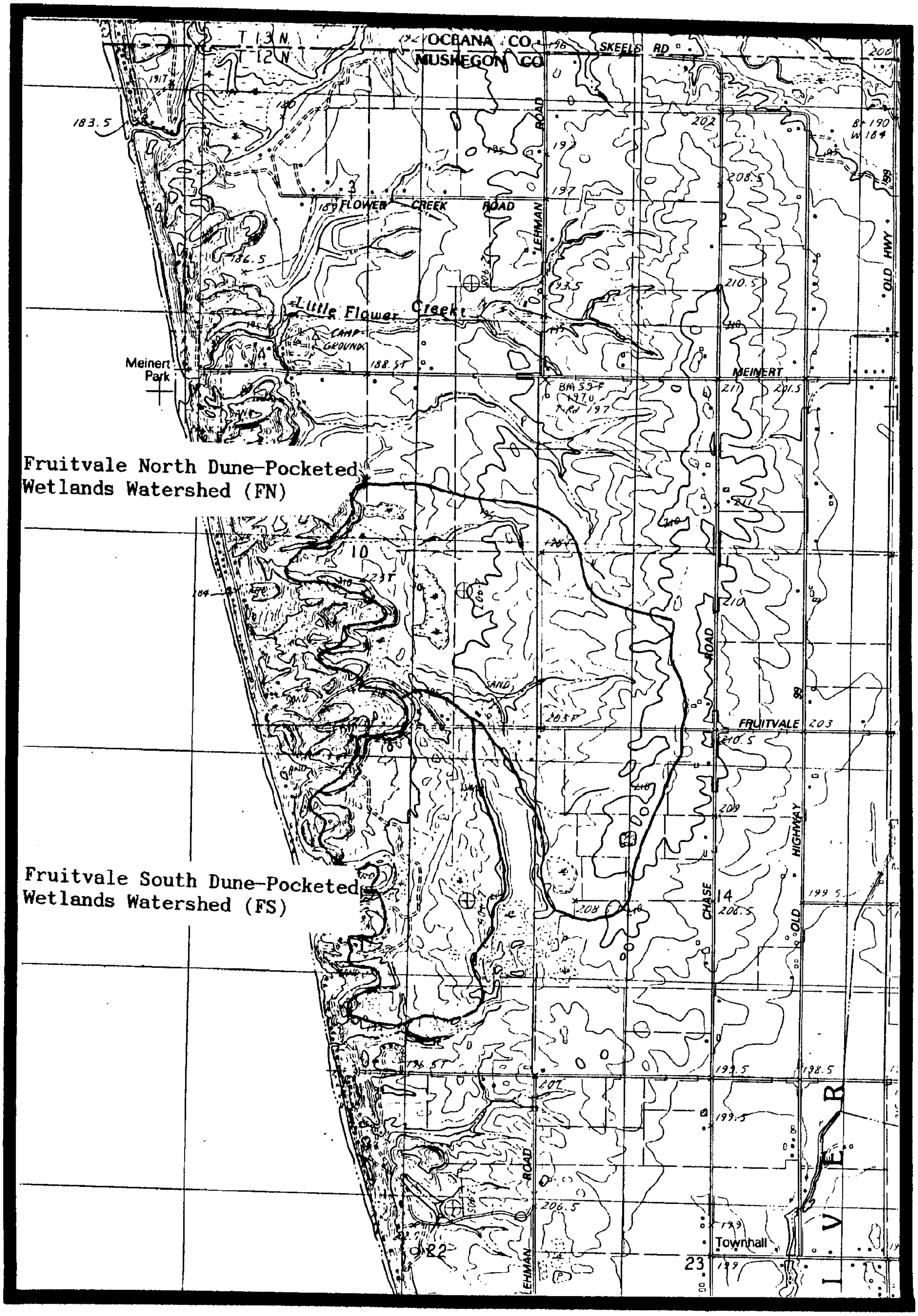


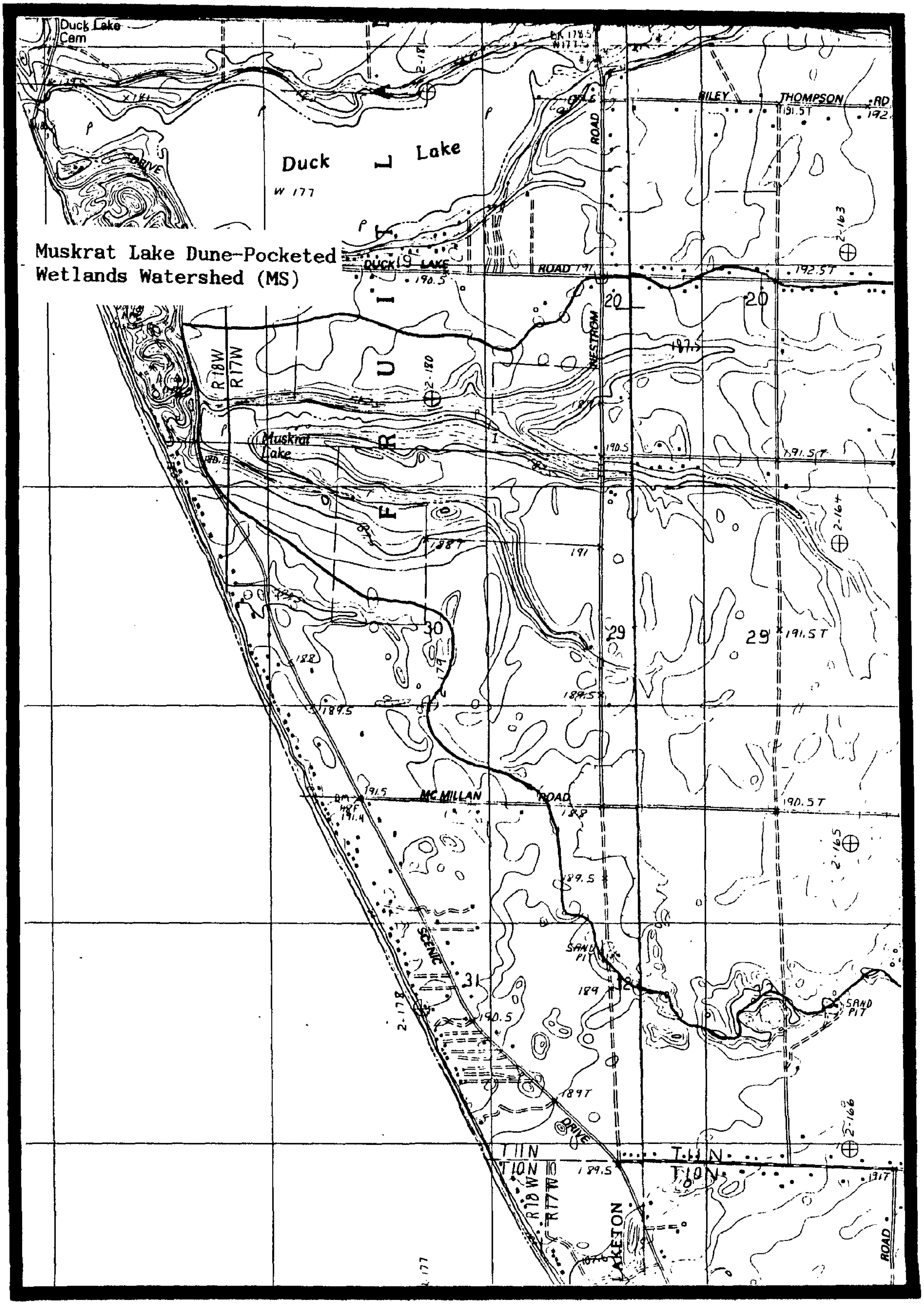
County Line Road Dune-Pocketed
Wetlands Watershed (CL)
Magoon
FILER
PHYLLIS
ROAD
T21N
T20N
MANISTEE CO
MASON CO
SASS ROAD
JEPSON ROAD
FREESOIL ROAD
OLD
Gurney Creek
NATIONAL FOREST
MORTON ROAD
TRAIL ROAD
SALT WELL

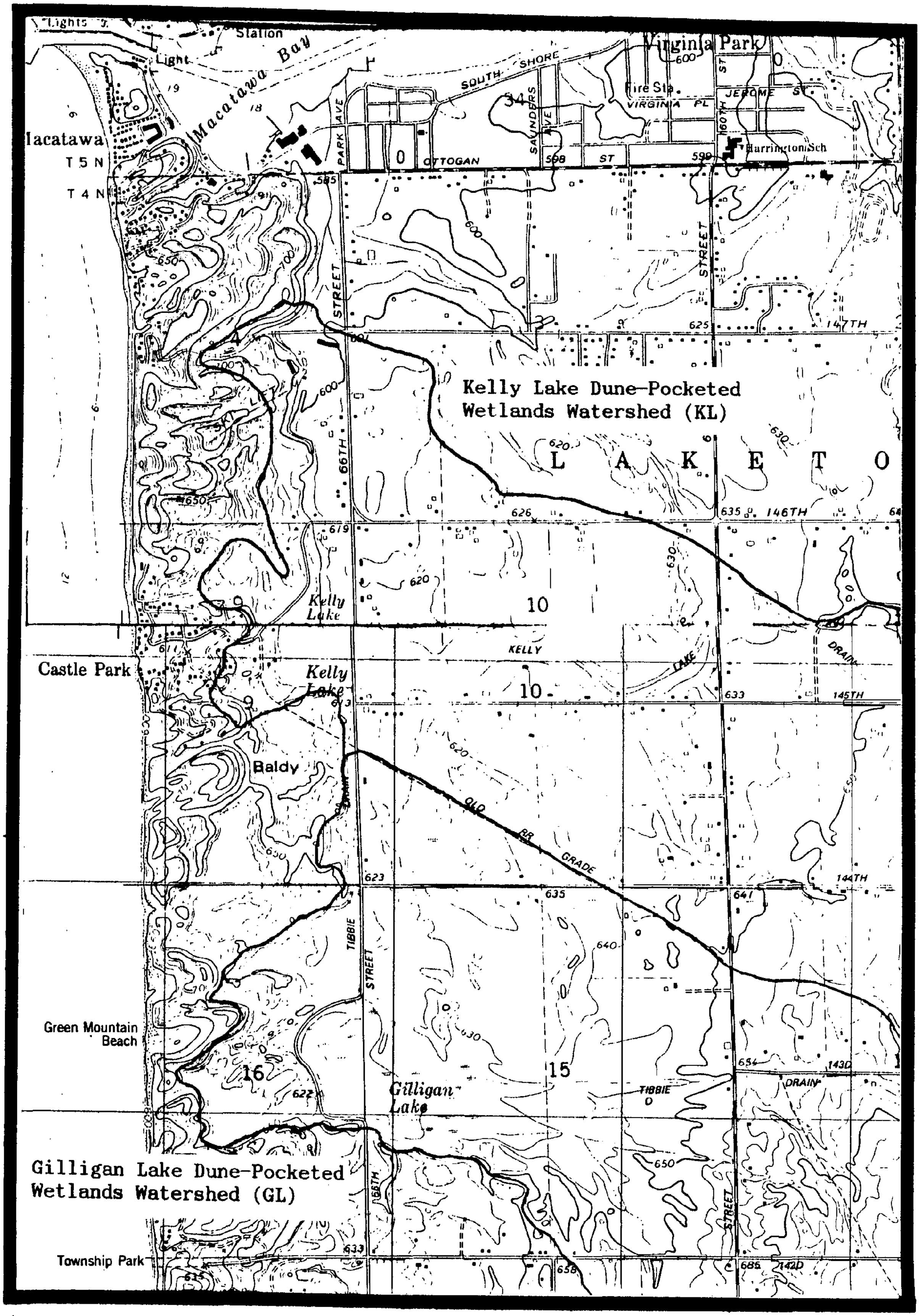

Spartina Marsh Dune-Pocketed
Wetlands Watershed (SM)
Nordhouse Lake Dune-Pocketed
Wetlands Watershed (NL)
LOOKOUT
STAIRS
Porter Creek
LAKE MICHIGAN
RECREATION AREA
24
26
25
35
36
G R A N T
MANISTEE NATIONAL
FOREST
ROAD
GREEN
Nordhouse
Lake
NURNBERG
ROAD
BDY
FOOTBRIDGE
FOREST BDY
W/L
L A K E
R18W
R17W

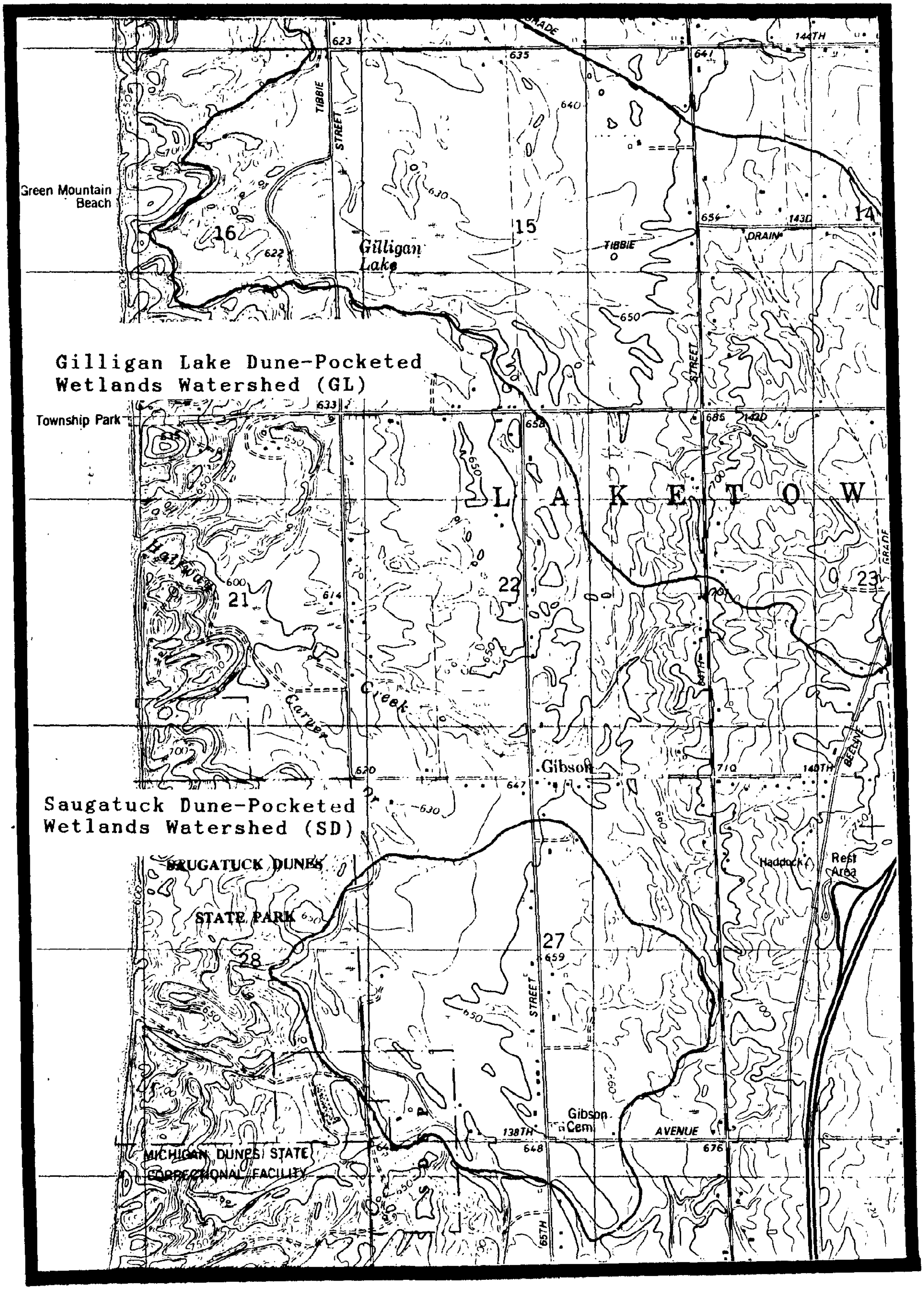

Bigsbie Lake Dune-Pocketed
Wetlands Watershed (BL)
4830
780000
FEET
4829
SHELBY
ROAD
4828
4827
Bigsbie
Lake
4826
35'
4825
LITTLE
SABLE
POINT
AVENUE
DRIVE

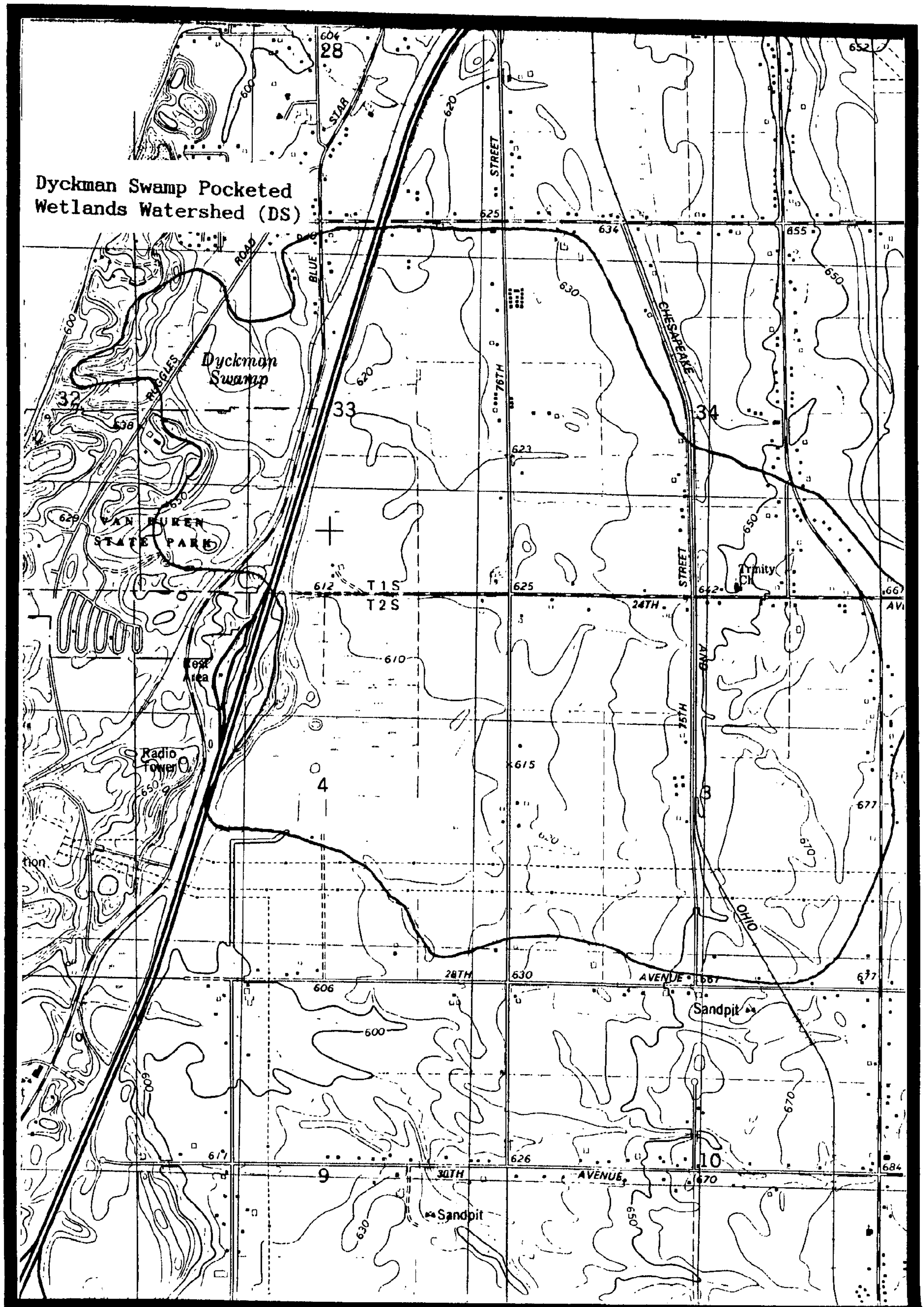

STONE ROAD
Stony Lake
STONY LAKE
Skinny Lake Dune-Pocketed Wetlands Watershed (SL)
Township Mem Park
Long Lake
Long Lake Dune-Pocketed Wetlands Watershed (LL)
36TH AVENUE
PARK ROAD
Whisky Cr
Pine Grove Cem
Townhall
TOWNSHIP PARK DRIVE
T 14 N
T 13 N
C L

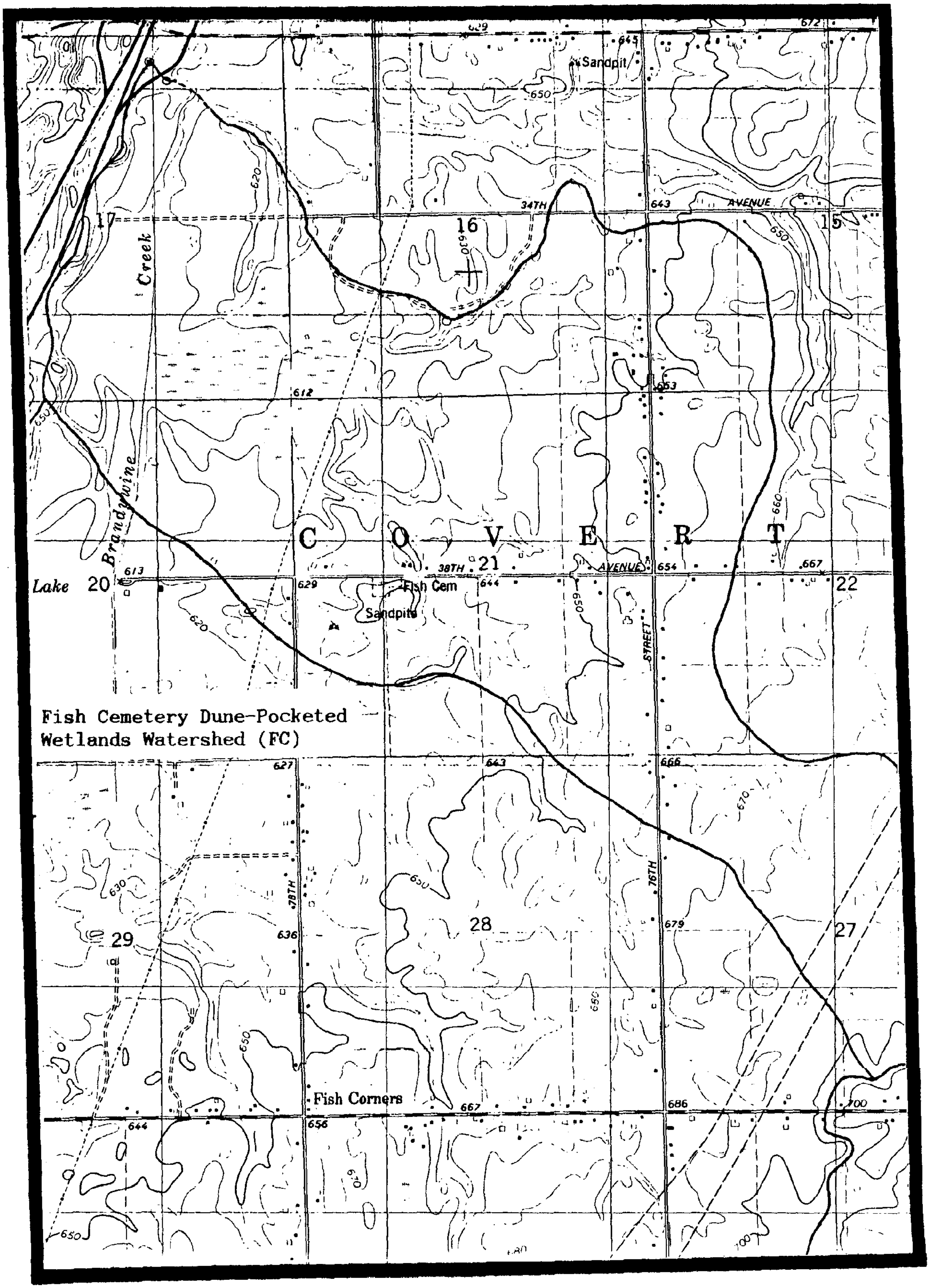

T 13 N
T 12 N
OCEANA CO.
MUSKEGON CO
SKEELS RD
FLOWER CREEK ROAD
LEHMAN ROAD
Little Flower Creek
CAMP GROUND
Meinert Park
MEINERT
OLD HWY
Fruitvale North Dune-Pocketed
Wetlands Watershed (FN)
CHASE ROAD
FRUITVALE
OLD HIGHWAY
Fruitvale South Dune-Pocketed
Wetlands Watershed (FS)
Townhall
LEHMAN
R
E
V
I

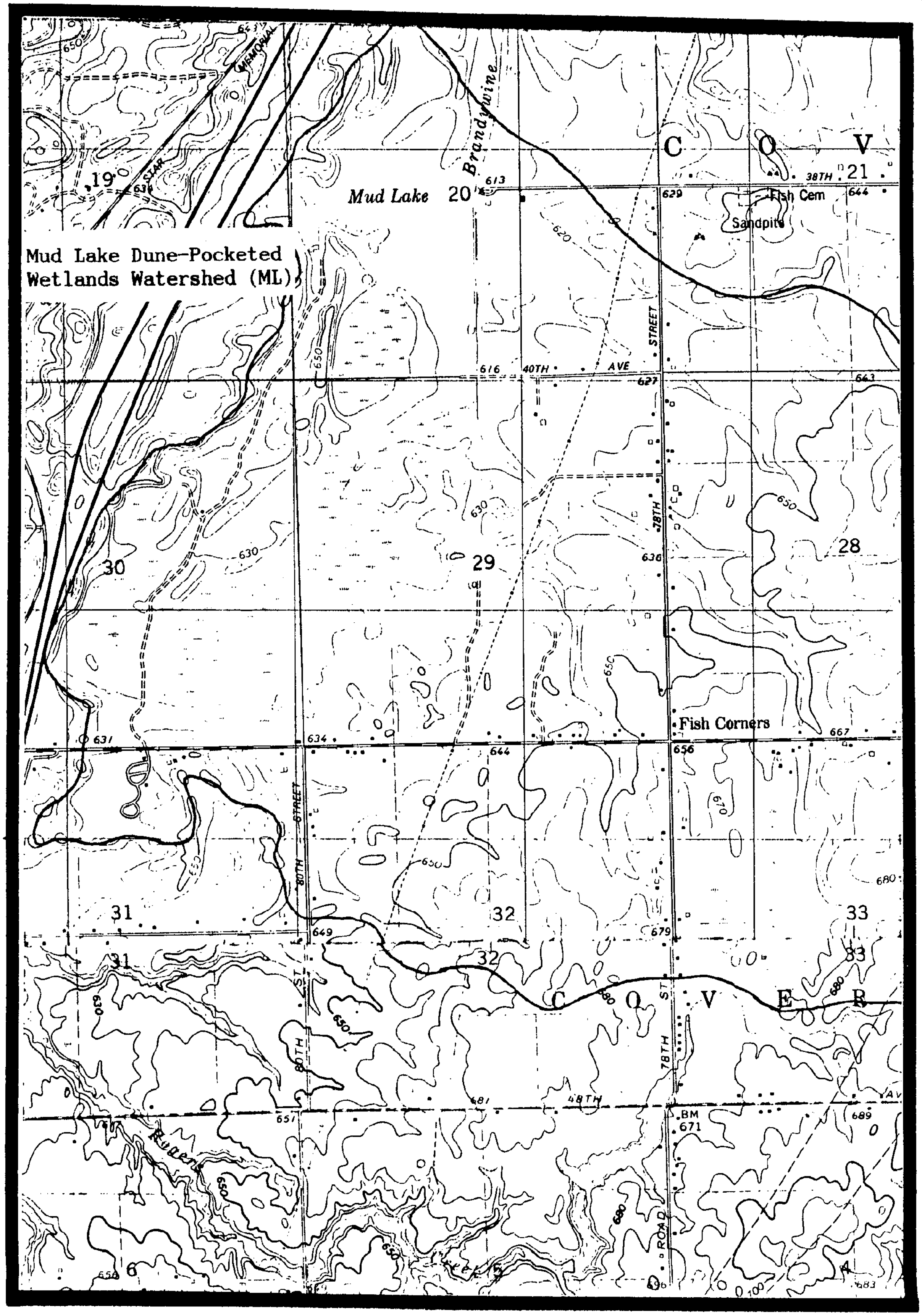

Muskrat Lake Dune-Pocketed
Wetlands Watershed (MS)
Duck Lake
Cem
Duck L Lake
Muskrat
Lake
DUCK LAKE ROAD
RILEY THOMPSON RD
MC MILLAN ROAD
SCENIC DRIVE
LAKETON
NESTROM
ROAD
SAND PIT
R18W
R17W
T11N
T10N
19
20
29
30
31

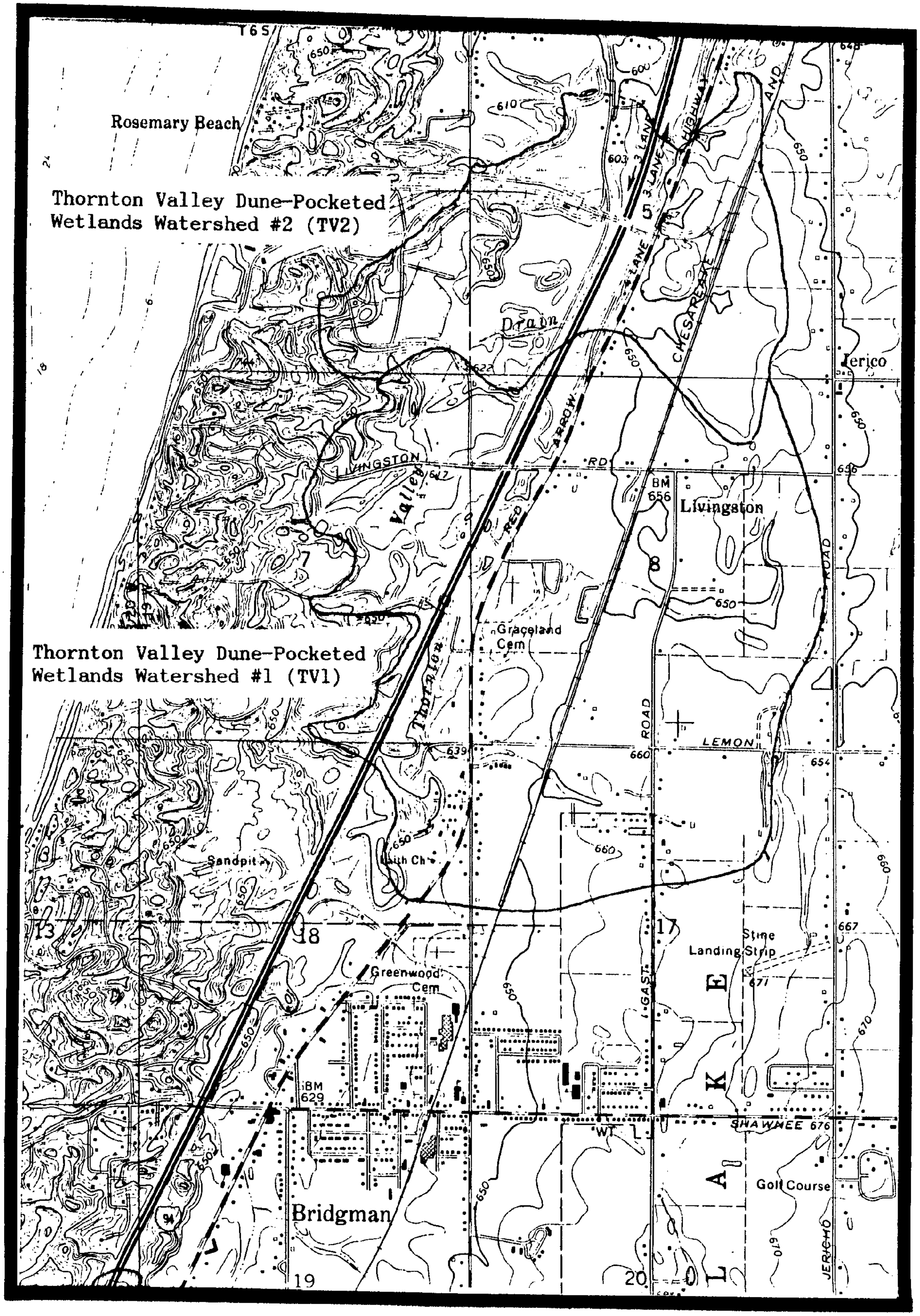

Kelly Lake Dune-Pocketed
Wetlands Watershed (KL)
Gilligan Lake Dune-Pocketed
Wetlands Watershed (GL)
Macatawa Bay
Virginia Park
Fire Sta.
Harrington Sch
SOUTH SHORE
VIRGINIA PL
JEROME ST
OTTOGAN ST
PARK AVE
SAUNDERS AVE
60TH ST
66TH STREET
T 5 N
T 4 N
L A K E T O
147TH
146TH
145TH
144TH
143D
142D
Kelly Lake
KELLY LAKE DRAIN
Castle Park
Baldy
OLD RR GRADE
TIBBIE STREET
TIBBIE DRAIN
Green Mountain Beach
Gilligan Lake
Township Park
10
15
16

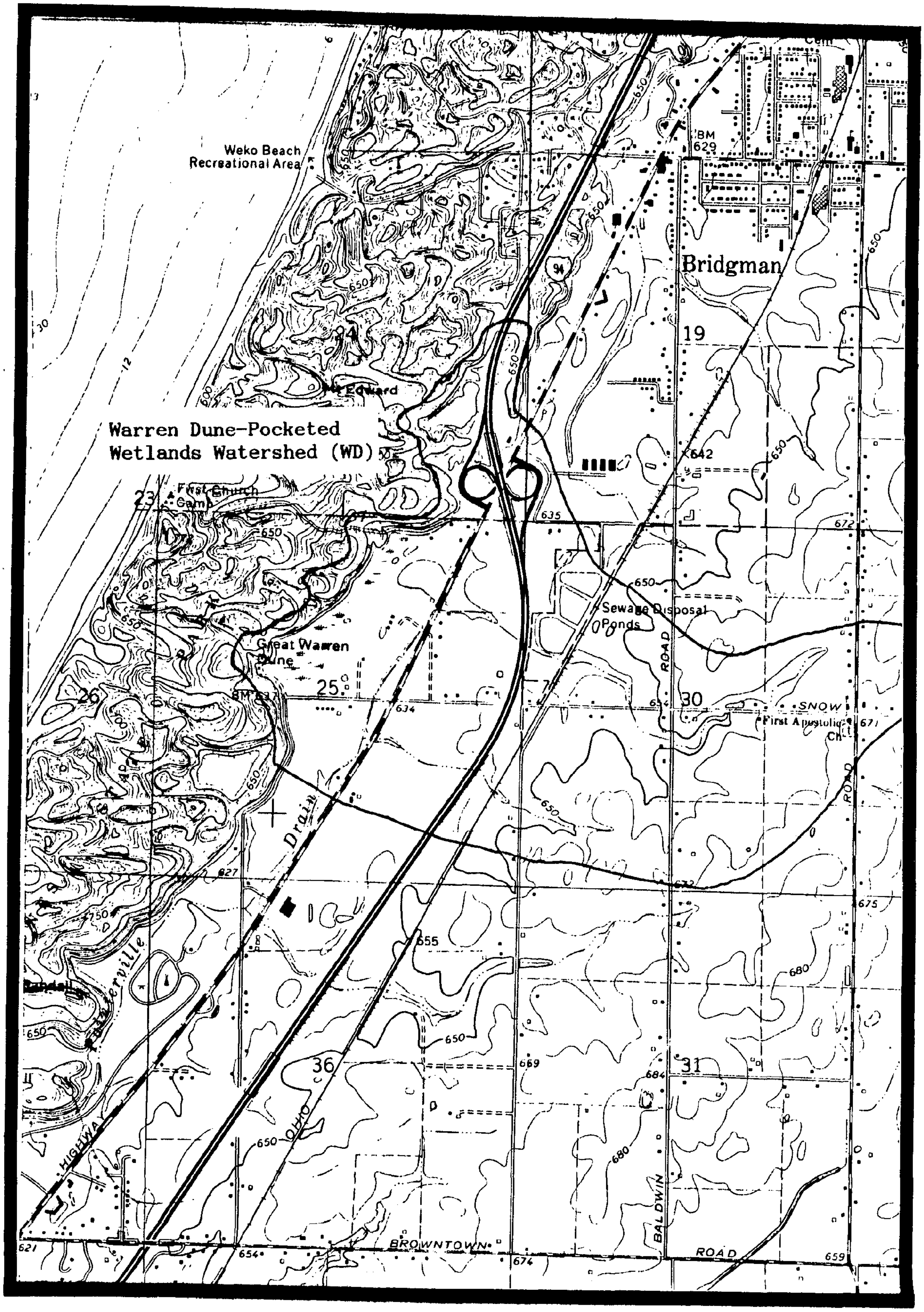

Gilligan Lake Dune-Pocketed
Wetlands Watershed (GL)
Saugatuck Dune-Pocketed
Wetlands Watershed (SD)
Green Mountain
Beach
Gilligan
Lake
Township Park
TIBBIE
STREET
144TH
143D
140D
140TH
DRAIN
GRADE
BEELINE
L A K E T O W
16
15
14
21
22
23
27
28
Carver Creek
Gibson
Gibson
Cem
Haddock
Rest
Area
SAUGATUCK DUNES
STATE PARK
MICHIGAN DUNES STATE
CORRECTIONAL FACILITY
138TH
AVENUE
65TH
STREET


Dyckman Swamp Pocketed
Wetlands Watershed (DS)
Dyckman Swamp
VAN BUREN STATE PARK
Radio Tower
Rest Area
T1S
T2S
STREET
76TH
BLUE STAR
RUGGLES ROAD
CHESAPEAKE AND OHIO
24TH
STREET AND 75TH
28TH AVENUE
30TH AVENUE
Trinity Ch
Sandpit
Sandpit
28
32
33
34
4
3
9
10


Sandpit
650
34TH
643
AVENUE
17
16
15
Creek
612
653
Brandywine
C O V E R T
38TH
21
AVENUE
654
667
Lake
20
613
629
Fish Cem
644
22
Sandpits
620
STREET
Fish Cemetery Dune-Pocketed
Wetlands Watershed (FC)
627
643
666
670
78TH
76TH
630
29
636
28
679
27
Fish Corners
667
686
700
644
656
650


Mud Lake Dune-Pocketed Wetlands Watershed (ML)
Mud Lake
Brandywine
MEMORIAL
STAR
C O V
C O V E R
19
20
21
28
29
30
31
32
33
6
5
4
38TH
40TH AVE
48TH
78TH STREET
80TH STREET
ROAD
Fish Cem
Sandpits
Fish Corners
BM 671


Rosemary Beach
Thornton Valley Dune-Pocketed
Wetlands Watershed #2 (TV2)
Thornton Valley Dune-Pocketed
Wetlands Watershed #1 (TV1)
Livingston
Jerico
Graceland Cem
Sandpit
Greenwood Cem
Stine Landing Strip
Golf Course
Bridgman
LIVINGSTON RD
LEMON
SHAWNEE
JERICHO ROAD
RED ARROW
CHESAPEAKE AND
Thornton Valley
Drain


Weko Beach
Recreational Area
Bridgman
Warren Dune-Pocketed
Wetlands Watershed (WD)
First Church
Camp
Sewage Disposal
Ponds
Great Warren
Dune
First Apostolic
Ch
BALDWIN ROAD
SNOW ROAD
BROWNTOWN ROAD
HIGHWAY
Drain
OHIO
19
23
25
26
30
31
36
BM
629
642
635
650
672
675
680
655
669
684
621
654
674
659
671
634
627