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A RESOURCE ANALYSIS OF DEVILS LAKE, NORTH DAKOTA

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David R. Givers and Jay A. Leitch*

I. PHYSICAL DESCRIPTION

The Devils Lake Basin (DLB), a hydrologic subdivision of the Red River Basin, lies within the central drift prairie (Figure 1) (Devils Lake Basin Advisory Committee 1976; Whitman and Wali 1975). The DLB includes 3,800 square miles or 5.5 percent of the state's surface area and is divided into nine watersheds that lie in nine counties.

DEVILS LAKE STATISTICS

Location:	Northeast Central North Dakota Longitude 99° West Latitude 48° North
Surface area:	48 sq. miles @ 1,425' msl
Watershed area:	3,320 sq. miles
Water volume:	385,000 acre feet @ 1,425' msl
Miles of shoreline (includes East Bay):	152 miles @ 1,425' msl
Maximum depth:	25 ft. @ 1,425' msl
Natural outlet to Sheyenne River:	@ 1,451 feet msl
Average growing season:	106-120 days
Average annual precipitation:	17 inches
Average annual evaporation:	30 inches

SOURCE: <u>Statistical Abstract of North Dakota 1979</u>; Swenson and Colby 1955.

Devils Lake is the largest natural lake in North Dakota. It is a unique inland aquatic ecosystem because of its natural high salt content. An 1852 map of the Minnesota Territory, which included part of North and South Dakota, shows the Devils Lake Basin as the "salt water region" (Meier 1981). It is a terminal lake because it no longer contains a functioning outlet and all drainage within the watershed terminates in the lake. Devils Lake is also a terminal lake from an ecological perspective because the lake will eutrophy in the long run. This is the natural sequence of events for lakes and occurs

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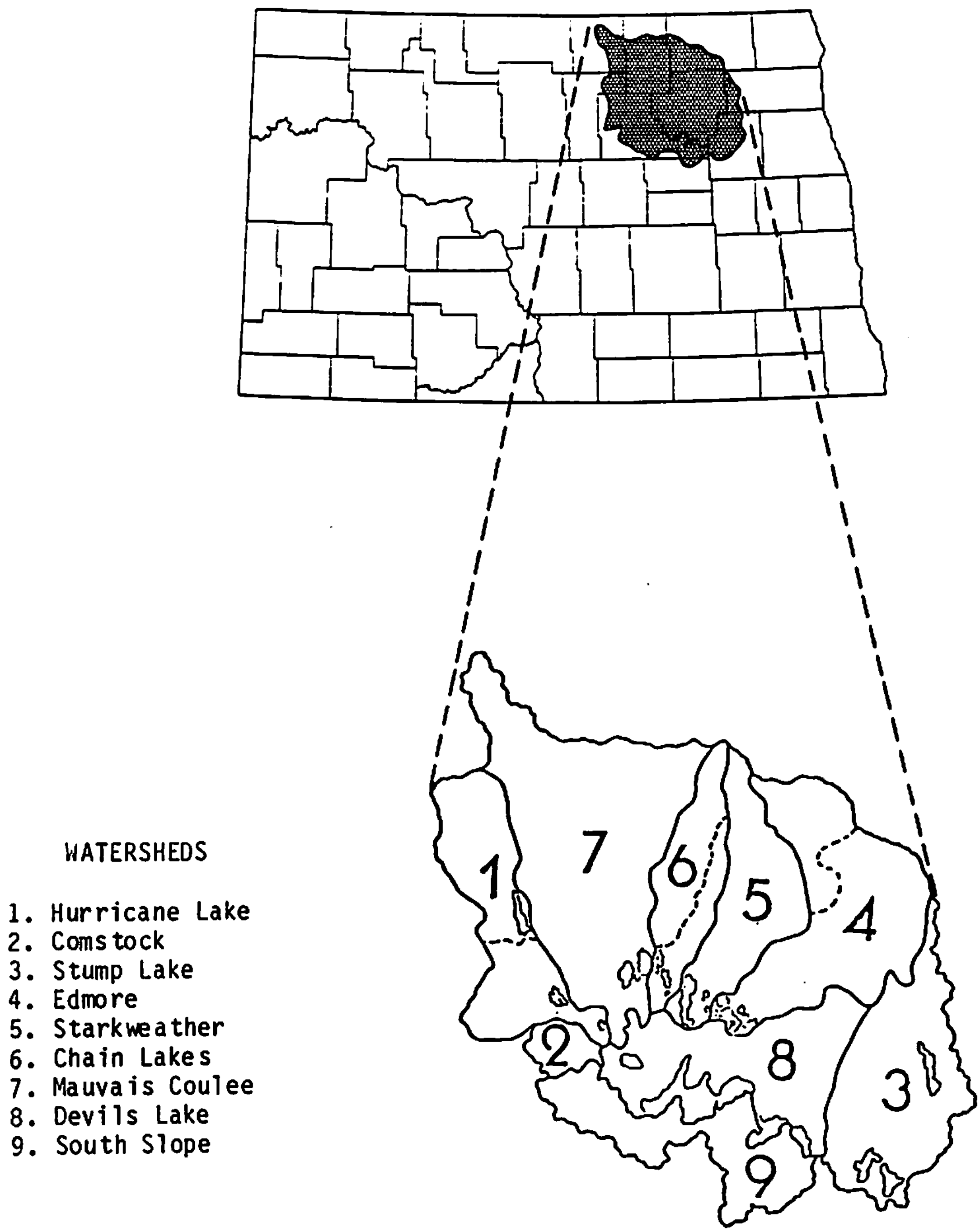

Figure 1. The Devils Lake Basin

SOURCE: Devils Lake Basin Advisory Committee 1976.

over an unspecified, but estimable, long period of time. In the interim, Devils Lake provides unique opportunities for management.

Management techniques for Devils Lake are unique because only about 5 percent of the North American land mass contains closed drainage basins (de Martonne 1927, in Wiche 1986). Within that category of terminal lakes a wide divergence of natural conditions exists. As an example, both Devils Lake and the Great Salt Lake of Utah are saline, but only Devils Lake currently contains a sport fishery. Therefore, within the classification of terminal lakes, management must be designed specifically to the site and also must include basinwide factors that impact management of the lake. In short, a resource management plan, in order to be effective over a long period of time, will be an ecosystem management plan.

Physiography

Numerous students of geology have described the history of the formation of Devils Lake beginning with Upham in 1895. As each subsequent writer adds to the body of knowledge, a more complete picture of natural forces in action and timing of those events is developed.

Devils Lake is the result of the interaction of large-scale geological and climatological forces. Geological processes have sculptured the land into a terminal lake and those same forces have dictated the type of soils and the location and extent of groundwater aquifers. In turn, soils and perhaps groundwater influence the nature and chemistry of water in the lake. Within the watershed, long-term weather patterns or climate have created periodic raising and lowering of the lake level, while once again, geochemical composition and mechanical action have contributed to the level of total dissolved solids (TDS) or salinity.

Area of the contributing watershed varies slightly depending on assumptions used to calculate contributing and noncontributing areas. This relative indeterminancy is to be expected and is mostly, but not entirely, of academic importance for researchers calculating runoff values, lake volumes, and storage capacity. Wiche (1986) estimates the size of the basin as 3,810 square miles with 3,320 square miles tributary to Devils Lake and the remainder to Stump Lake.

Prior to glaciation, drainage was northward and northeastward throughout all of present-day eastern North Dakota (Bluemle 1981, 1983). As glaciation advanced southward, drainage was blocked and ultimately covered over with glacial drift and lacustrine (lake) sediments.

There were several periods of growth and recession of the glaciers (researchers have documented at least four major thrusts and there may have been others), and each time this occurred large lakes formed at the front of the glacier as the glacier advanced and retreated. One of those glacial lakes in the study area was Lake Minnewaukan, which was about three times the current size of Devils Lake. An excellent description of the large-scale mechanical forces, which produced the topography surrounding Devils Lake, was described by Bluemle (1981).

The outlet for glacial Lake Minnewauken was into the Sheyenne River and was at elevation 1,451 - 1,453 feet (msl). As the glacial lake receded from that level there was no longer an outlet, and the basin became closed or without an outlet to a larger basin.

Lake Levels

Lake levels are an important element in a potential management program. Because Devils Lake has both an historical and an inferred record of extreme variability affecting the salinity and productivity of the lake, an understanding of lake levels is important to the lake manager. In addition, it appears that lake level is an independent variable that is not easily manipulable by any action currently available to the manager.[1] Also, any lake level manipulation could impact water chemistry and fisheries productivity.

Prehistorical levels have been described by several authors including Aronow (1957), Bluemle (1983), Callender (1968), and Van Alstine (1980). A graphic representation of the variation in lake levels was given by Callender (1968) and since modified by Bluemle (1983) and Wiche et al. (1986). When estimated annual precipitation exceeded 15 inches, the lake tended to be fresh and when precipitation was less than 15 inches, it was saline (Figure 2). Over the past few years, the lake has tended toward fresh rather than saline, but less than 500 years ago it was very saline.

Lake level has varied between 1,440 feet above mean sea level 8,500 years ago to as much as 1,453 feet near the beginning of the Pleistocene Age, which may have been as recent as 12,000 years ago (Bluemle 1981). For more recent times, Upham (1895) estimated the water level as 1,441 feet in 1830 based upon tree-ring chronology of a dense stand of trees that were growing at that level while there were none below that level. Water levels have been recorded since 1867, although at times record keeping was less methodical than researchers prefer.

The lowest recorded level was 1,400.9 feet in 1940 (Wiche et al. 1986). The lake recovered from that level until 1956, then declined until 1968. From that time it has continued to climb to its highest recorded level of this century, and is now standing at just under 1,429 feet.

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[1]The U.S. Army Corps of Engineers is currently studying alternative plans to control the level of Devils Lake (U.S. Army Corps of Engineers 1988).

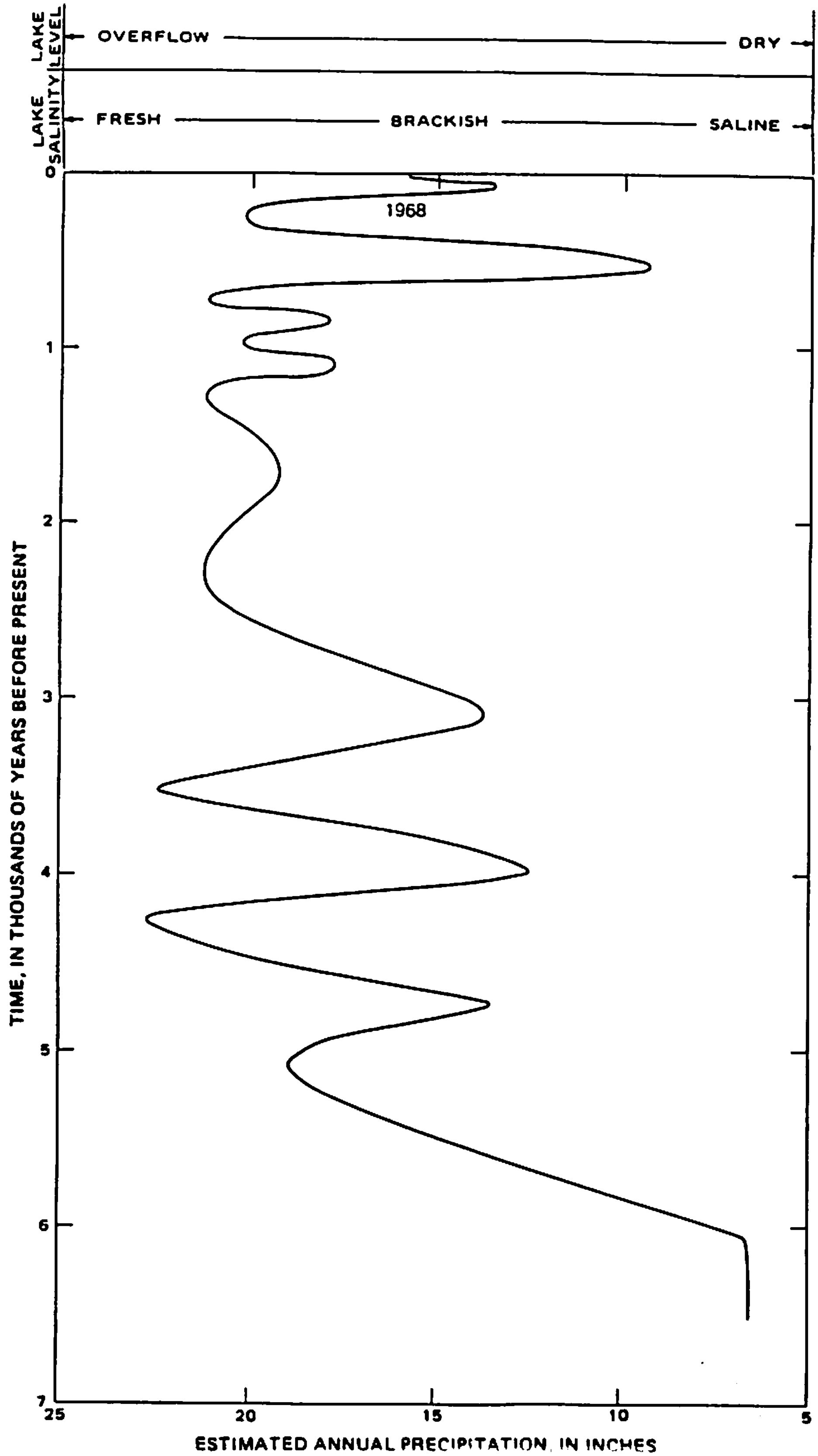


Figure 2. Estimated Prehistoric Annual Precipitation (taken from Wiche et al. 1986, who modified Callender 1968).

Mass Balance and Lake Levels

Langbein (1961) studied both salinity and hydrology of several closed lakes including Devils Lake. He used the water balance equation:

$$I + PA_L = E'A_L$$

where

I is inflow

P is precipitation

A_L is lake area, and

E' is gross evaporation

Langbein derived a die-away constant or k factor, which is time dependent. The k factor is the ratio of the change in lake volume to the rate of discharge. The theoretical response time is 14 years for Devils Lake: given the sum of all hydrologic and climatologic factors, any given yearly event should not have an immediate effect on the lake. Various researchers, including Langbein himself, postulated why actual response does not necessarily follow the theoretical value. For example, between 1867 and 1940 the level of the lake dropped about 35 feet, an amount that was not solely explainable by the decline in precipitation. Until recently, some observers postulated that intensive farming may have had an impact on lake levels during that period. Now consensus opinion seems to center around climatic changes as the single most important factor affecting lake level.

Langbein (1961) also postulated that one of the climatic variables, which is shown in the equation above as E', evaporation, changed due to a rise in atmospheric temperature. This climatic variable would change both lake evaporation and evapotranspiration from the land, which in turn affects runoff into the lake. However, Woodbury (1986) found no apparent statistical correlation between lake level and evaporation. He admits there may be some question of the validity of this conclusion because of the nature of the derived mathematical relationship and use of scattered monthly recorded data. The only definitive statement that can be made is that evaporation exceeds precipitation (Joranstad and Dando 1977).

A discussion of response time of the lake and inflow (I) would not be complete without reference to the role of the potholes and chain of lakes surrounding the main body of water.

> One cannot underestimate the capabilities of the natural basin storage to dampen and alter the timing and volume of runoff reaching Devils Lake. Such basin behavior provides a physical explanation for the persistence and long-term memory ... for Devils Lake. (Woodbury 1986, p. 94).

Thus it would appear that upstream characteristics, although not as significant as climate, remain important to the timing of water levels in the lake. The value of upstream storage is illustrated from estimates made by Wiche et al. (1986) that showed that during 1965 to 1967 upstream lakes provided 112,000 acre-feet of storage and that without this storage the lake would have been theoretically 6.8 feet higher than its recorded level.

Groundwater and Lake Levels

An additional factor affecting lake levels included in the I term in the above equation is groundwater flow. Discussion about groundwater has occurred, but not much agreement has been reached. Swenson and Colby (1955) used data from the Sheyenne River at Sheyenne, North Dakota, to estimate that changes in groundwater storage would account for 5 percent of the changes in the volume of the lake. Callender (1968, p.21) stated:

> No definite conclusions regarding groundwater inflow to Devils Lake can be made from the water budget data except groundwater flow probably accounts for 20 percent of the total balance of Devils Lake. This figure will vary according to the hydrological conditions in the recharge area.

Callender's estimate was based on data taken from Big Coulee, which may be more appropriate than data from Sheyenne, North Dakota.

Wiche (1986) found no agreement among researchers regarding the effect of groundwater; some have concluded that there is a relatively impermeable layer in the bed of Devils Lake, which allows very little hydraulic conductivity. Bluemle (1987) stated that the groundwater contribution could be as little as zero or as much as 30 percent.

Although present-day researchers cluster their opinions around more recent writings, it is still useful to return to some of the original observers such as Simpson (1912). At the turn of the century the lake stood at approximately 1,422 feet and Mauvis (Big) Coulee was dry. Simpson noted that the climatic dryness and the morainal character of land immediately surrounding the lake inhibited runoff and flow into the lake from localized rainfall. He postulated that the only source of water keeping the lake from completely drying out at that time had to be groundwater.

Ferguson (1984) documented a groundwater gradient or flow between Wood Lake and the underlying aquifer, although there is no transference of conclusions from Wood Lake to the question of groundwater flow into or out of Devils Lake. The direction of groundwater movement is from the southwest into the west side of Wood Lake and out of the lake along the east shore and towards the northeast.

Lake Levels and Modeling

Several researchers have worked with models of Devils Lake in an effort to describe and predict potential lake levels. Parekh (1977) and Leapaldt (1980) each used physical models adapted from the Stanford Watershed Model. The purpose of the model is to simulate the effects of short-term events and predict response on the lake. The required data base is extensive and unfortunately not all the subbasins in the watershed had gauging stations, which would have made the results more useful to planners and managers.

A different mathematical approach to describe the effects of basin events on lake levels was taken by Padmanabhan et al. (1984) and Woodbury (1986). Woodbury, as well as Wiche (1986), concluded independently from the work they both cited by James et al. (1979) that an ARMA (auto-regressive, moving average) model would provide the best description of future water-level probabilities.

There are limits to Woodbury's study because the frequency of probability, as defined by Woodbury, means that it is not possible to predict a given lake level in a given year:

> In summary, the lake-level frequency relationship...is considered most applicable for flood insurance purposes, future development planning, and the planning of flood hazard mitigation measures (Woodbury 1986, p.201).

Appendix A is Woodbury's histogram needed for estimating flood-level probabilities.

Wiche et al. (1986), also developed an annual exceedance probability, using a starting lake level, storage characteristics, and lake volumes. In addition, Wiche (1986) studied the interaction of hydrology and climatologic events using a linear regression model. He found little correlation, given the limits inherent in the model, between annual discharge and winter precipitation and concluded, "Apparently, <u>other climatologic variables</u> [emphasis added] such as antecedent moisture, temperature during the snowmelt, and wind velocity affect the amount of runoff derived from a given snowpack." (Wiche 1986, p. 32). He developed a refinement for the model based on work by Miller and Frink (1984), which included an antecedent moisture index, a winter temperature index, a snowmelt index, one-year lag volume, and a land-use factor, which would change the model to a more complex or multiple regression model. However, the applied value of this more complex model may be limited because precipitation and flow records are incomplete.

Given the limitations of modeling, Wiche (1986, p. 19) provides a generalized description of lake events derived from the period 1980-83:

(1) During late fall, the water level in Devils Lake declines to a minimum and remains relatively constant from freeze-up until spring thaw.

(2) Snowmelt and rain in March through May produce runoff from the basin into Devils Lake. The maximum water level occurs in April or May in drier years and June or July in wetter years.

(3) Sometime in April through July, outflow (primarily evaporation) exceeds the inflow, and the water level starts to decline to a minimum in late fall or early winter. Then the cycle is repeated.

Short-term events can drive the lake away from this general model. Wiche describes these in his study as intense and/or out-of-season rainfall. The dry years such as the 1930s also contained such short-term events as did 1954. The most recent rise, 1969 to date, has yet to be explained more fully by modeling theory and is not discussed here. The response time or k factor as derived by Langbein (1961) and discussed above is notably missing from any of the model equations. That 14-year theoretical lag factor, which may have changed somewhat due to human activity, appears to match the 1969 to 1984 period.

Interaction of Climate, Hydrology, and Lake Levels

Wiche (1986) concluded that there is little likelihood of establishing good statistical relationships between Devils Lake water-levels and climatologic variables. Consequently, he grouped water levels into 10 major lake-level fluctuations (Table 1). He then gives a more qualitative description of event levels and finds:

> Although water-level fluctuations seem to show good correspondonce to climatologic variables of precipitation and temperature of five years or more, there are periods that do not show good correspondence ... for instance 1969 to 1980 when ... apparently other factors such as changes in basin storage, changes in contributing and noncontributing drainage area, the timing of snowmelt, and antecedent moisture conditions caused an increase in water levels at a time when water precipitation did not increase significantly (Wiche 1986, p. 37).

The most compelling evidence that the major factor controlling lake level is climate is provided by Reinartz (1984 in Woodbury 1986) and shown as Figure 3. The fit of the curves is simply too good to be ignored. This data, combined with Wiche's (1986) discussion of short-term events causing a change in lake level, should leave little doubt that climate is the driving force.

Salinity

Because Devils Lake is a closed lake, subject to climatic variables, lake levels are interrelated with the salinity or freshness of the water. Devils Lake according to Callender (1968, p. 48) is classified as a "sodium-calcium-magnesium-chloride sulfate type of water. Sodium and sulfate

TABLE 1. MAJOR LAKE-LEVEL FLUCTUATIONS OF DEVILS LAKE

Years	Comparative Water-Level Fluctuations	Water Level (feet above sea level)
1867-1884	High lake level	1,438.0 - 1,434.4
1885-1890	Rapid decline	1,434.4 - 1,424.6
1891-1906	Constant lake level	1,425.0
1907-1930	Gradual decline	1,424.6 - 1,411.4
1931-1940	Rapid decline	1,411.4 - 1,402.3
1941-1949	Gradual rise	1,402.3 - 1,407.3
1950	Rapid rise	1,407.3 - 1,414.9
1951-1957	Gradual rise	1,414.9 - 1,418.2
1958-1968	Gradual decline	1,418.2 - 1,411.7
1969-1983	Rapid rise	1,411.7 - 1,428.1

SOURCE: Wiche 1986.

account for 75 percent of the total dissolved solids...(and is) therefore properly classifed as a sodium-sulfate type ..."

Callender's analysis of salinity levels over prehistoric time is relied upon heavily by subsequent researchers to describe water levels. Van Alstine (1980) studied ostracods, a small bivalve animal with a shell, and discovered, for the most part, similar fluctuation of lake levels over prehistoric time. His work is based on population levels that are related to temperature and total dissolved solids or salinity.

Callender (1968) determined that the lake was last fresh from 122 to 200 years ago. This gives the last freshwater period as 1840. Upham (1895) reports that in 1830 the lake stood at 1,446 feet, which is not far below the Pleistocene overflow level when the lake also would have been fresh.

Langbein (1961) made an important contribution to understanding the cyclic relationship of salt content and lake volume or levels. He postulated an idealized cycling of salts which explains why the lake does not become increasingly salty over time. The level of dissolved solids does not increase or decrease in a direct or linear relationship. Langbein's theoretical cycle is shown in Figure 4, and the actual sequence is shown in Figure 5.

A net loss of salts from solution is thought to occur during the receding phase of the lake. Callender (1968) also showed that salinity decreased as the volume of water decreased from 1899 to its low in 1948. The mechanism for this is thought to be the result of several mechanical and chemical processes. Basically, salts are precipitated out of solution as the lake recedes, are bound-up chemically, and are not easily resoluble. Trapped

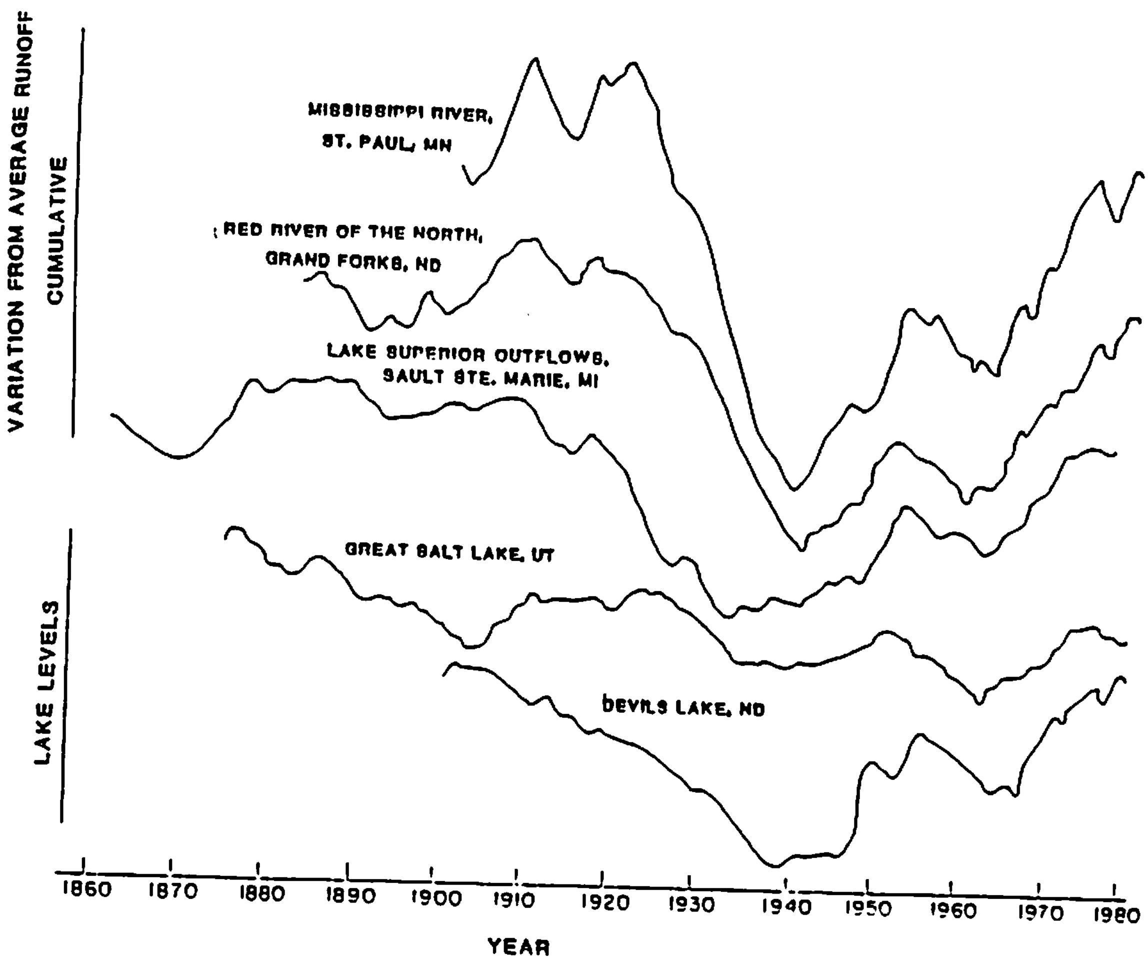
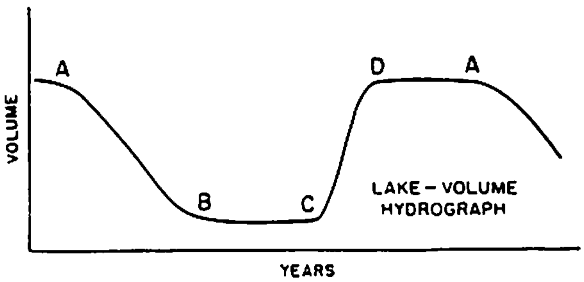


Figure 3. Regional Historic Variations in Lake Levels and Runoff.

SOURCE: Reinartz 1984 (taken from Woodbury 1986).

salts are also transported by wind out of the area. The result is that as the lake refills towards its prerecession level, the total volume of salts in solution does not necessarily reach the same level as when recession or drying up of the lake began. The final section, D → A in the theoretical diagram (Figure 4), would take place over a long, unspecified period of time. During this phase the lake should reach a high water volume and the annual input of salts to the lake would be expected to exceed losses so that once again the result is another loss of fish population such as occurred from 1890 to 1910 or essentially the movement from D → A.

To summarize the functioning of this cycle, it is important to keep in mind that it is not the refilling of the lake in and of itself that reduces salinity. Rather, it is the complex cycling of a terminal aquatic ecosystem, which first operates to reduce the salt content after which a rising lake level can once again provide freshening water. This is the true "mechanism"



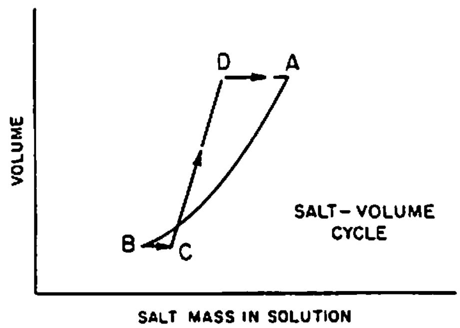


Figure 4. Schematic Variation of Salt Tonnage in Solution with Fluctuations in Lake Volume.

SOURCE: Langbein 1961.

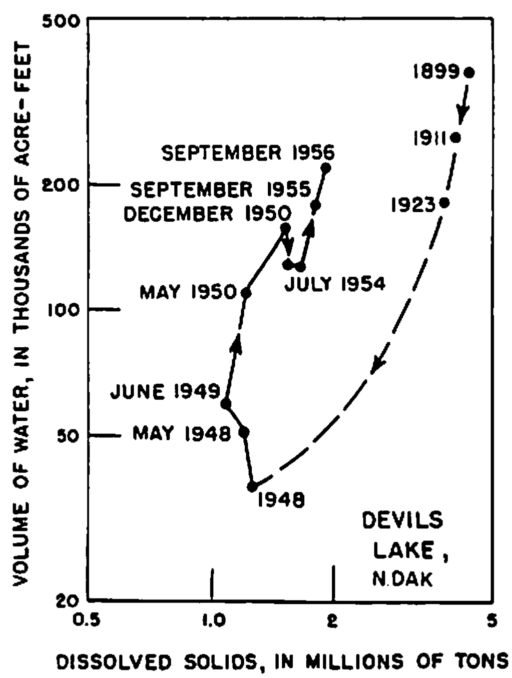


Figure 5. Variation of Salt Content with Water Volume

SOURCE: Langbein 1961.

regulating Devils Lake and other similar systems. Therefore, the simple generalization that more water freshens the lake is incomplete and may mislead lake managers. Ironically, for the lake manager, it is the long stable period of high lake levels that ultimately leads to the demise of the fish population and their supporting food web. This system has functioned for at least 7,000 years, cycling between fresh and saline phases.

Langbein (1961) estimates the stable high-water-level phase for Devils Lake to be 800 years. He notes that using data from Swenson and Colby (1955) to input his derived equations, that phase A → D (Figure 4) results in 2,100 and 2,200 years as the salt-accumulation time. The disparity is not important here, but it suffices to say that this phase of the lake is long from the human perspective.

Water Quality

Water quality standards for the Devils Lake Basin have been established by the North Dakota State Department of Health. These standards are issued under rule 33-16-02 of the North Dakota Administrative Code as adopted January 16, 1985, and effective April 1, 1985. The purpose of the rule is to "maintain, improve, or both, standards of quality and purity of waters of this state." Incorporated into this water quality policy is North Dakota Century Code section 61-28-01 which reads as follows:

> It is hereby declared to be the policy of the state of North Dakota to act in the public interest to protect, maintain and improve the quality of the waters in the state for continued use as public and private water supplies, propagation of wildlife, fish and aquatic life, and for domestic agricultural, industrial, recreational and other legitimate beneficial uses, to require necessary and reasonable treatment of sewage, industrial, or other wastes.

Standards of water quality for lakes are based upon lake classification. Numbers differentiate between types of fisheries and a letter describes the general characteristics or condition of the lake. Devils Lake is classified as 3C--a warm-water fishery presently somewhat degraded and progressing toward further degradation.

Total dissolved solids (TDS) is a general measure of water quality. Recent measurement of TDS is provided in Appendix B. Additional parameters defined by Administrative Code Rule 33-16-02 are important characteristics needed to assess the biological health of a particular water body. For example, the level of nutrients in a lake is a determinant in the amount of growth produced by plants and algae. An abundance of nutrients such as phosphorus and nitrogen will produce a high growth rate of aquatic plants and algae, ultimately leading to eutrophication.

The current levels of nutrients in Devils Lake assure that eutrophication will continue. Even though not all nutrients entering the lake remain in solution, excess amounts remain available. The rate of eutrophication can be reduced with management.

Schwindt (1987) estimates that 700 tons of phosphorous and 3,000 tons of nitrogen are in solution in Devils Lake. He lists the source of these nutrients as:

1. Nonpoint runoff from agricultural areas
2. Sediments that release nutrients during anoxic periods
3. Waterfowl and wildlife
4. Municipal sewage treatment systems
5. Atmospheric deposition
6. Nitrogen fixation from some types of blue-green algae
7. Possible groundwater contributions

Items 3 and 4 combined contribute less than 10 percent of the total phosphorous loading of the lake. The contributions of the other sources of nutrients need to be estimated before a lake management plan can be fully implemented. The most likely source for large contributions of nutrients is item one, but this may not be the only important source.

An additional study area is the effect that adding water from the Missouri River through the Garrison Diversion Project would have on algae populations. Some have questioned whether freshening changes the species of algae present or the growth rates of algae (Schwindt 1987).

The Sportfishery

Northern pike (Esox lucius), a primary game fish, disappeared from Devils Lake in 1889 (Pope 1906 and Farmer 1973). Loss of northern pike was partly due to Lakes Irvine, Dry, Sweetwater, and Chain freezing dry in 1889 (Pope 1906). Loss of spawning areas in Mission and Creel Bays was due to increasing deterioration of water quality, supposedly due to human settlement and subsequent development of the territory. Deficient precipitation also contributed to extensive migration and extermination of northern pike (Pope 1906).

The North Dakota Game and Fish Department attempted to reintroduce northern pike into Devils Lake by releasing 32,000; 50,000; and 1,075,000 pike fingerlings in 1955, 1956, and 1958, respectively. In 1958, nettings yielded 102 northern pike that averaged 19.6 inches and 2.5 pounds. In 1959 only three northern pike were recovered, averaging 25.3 inches weighing 4.6 pounds. Low oxygen conditions due to heavy ice cover in the shallow lake may have resulted in the failure of these northern pike plantings (Farmer 1973). In June 1967, 20,000 northern pike fingerlings were released in Creel Bay. By

September 1 the average length of the northern pike was 13 inches. Because of the success of the 1967 release and due to the increase in water level, the North Dakota Game and Fish Department in 1969 and 1970 initiated additional stockings of northern, walleye (Stizostedion vitreum) and perch (Perca flavescens). By 1972, summer anglers at Devils Lake were catching 9 to 11 pound pike and 2 to 4 pound walleye (Farmer 1973).

Devils Lake became known as a northern pike, walleye, and yellow perch lake during the past decade (Mitzel 1982, 1983). Numerous fishing tournaments have been held there with prizes totaling many thousands of dollars.

Species stocked in Devils Lake by the North Dakota Game and Fish Department include northern pike, walleye, yellow perch, white bass (Roccus chrysops), crappie (Pomoxis spp), striped bass (Roccus saxatilis) and muskie (Esox masquinongy). Muskie and striped bass have never shown up in test nets nor have they been reported by fishermen.

Recreational fishing is the major use of Devils Lake and serves as an important source of revenue and jobs for the local economy. Schwinden and Leitch (1984) studied the economic impact of the sportfishery using onsite interviews and mail surveys to obtain data on socioeconomic variables and expenditures. Three categories of anglers were defined as local, nonlocal, and nonresident.

Recreational fishing has a high participation rate and numbers generally about ninth in nationwide participation (Van Horn 1986). In North Dakota, Devils Lake is an important recreational resource with nearly half (48.3%) of the total statewide northern pike catch coming from Devils Lake during the 1974-75 season (Devils Lake Basin Advisory Committee 1976).

Schwinden and Leitch (1984) estimated the number of fishing days that occurred in the 1983-84 season (Table 2). Based on expenditures and fishing days, the estimated economic value of sportfishing to the regional economy was from $9.2 million to $28.0 million depending on assumptions (Table 3). An input-output model was used to estimate secondary employment. A total of 730 jobs have been created by the sports fishing industry.

The $28 million in business activity could be considered an optimistic scenario in which local and regional fishing expenditures are included to estimate the impact of sportfishing on the local economy. If one wishes to characterize the sportfishery as strictly an "export" market driven by nonresident anglers only, then no new wealth is generated by local and regional anglers. An economic development planner must be made aware of the three scenarios when planning to capture revenues from this activity.

TABLE 2. ESTIMATED NUMBER OF FISHING DAYS AND NUMBER OF ANGLERS BY TYPE THAT FISHED DEVILS LAKE, NORTH DAKOTA, 1983-84 SEASON

	Summer			Winter		
	Number of Anglers	Average Days	Total Days	Number of Anglers	Average Days	Total Days
Local	5,400	14.25	76,950	2,100	13.0	27,300
Nonlocal	9,200	15.0	138,000	9,200	7.5	69,000
Nonresident	4,000	5.6	22,400	4,000	2.0	8,000
			237,350			104,300

SOURCE: Schwinden and Leitch 1984.

II. SOCIOECONOMIC SETTING

Population and Retail Trade Area

The city of Devils Lake is the largest in the six-county area, and likewise is the predominant trade and service center (Owens et al. 1969, Coon et al. 1986). It is the center of State Region 3 (Figure 6), which had a total population of 48,411 in 1980. The city of Devils Lake has had a population of around 7,400 for the last ten years. The Devils Lake Trade Area represents a population of about 18,000 (Mortensen 1988), sufficient to support a viable retail trade sector.

Transportation

Devils Lake is accessible by highway, rail, and air. A major highway, U.S. #2, runs east to west across the north shore of the lake and through the city. The city is currently served by Amtrak passenger service. The municipal airport's 5,509-foot, lighted runway is served by one scheduled commuter airline.

Economic Base

Crop sales comprised the major share of Region 3's economic base for the 1958-1984 period. The household sector was the second largest contributor, while the construction, processing, trade, and services sectors did not contribe an important share (Coon et al. 1986). The high degree of dependence on crop production has limited real growth of the region's economy to somewhat less than that of other regions having broader resource bases and larger populations.

TABLE 3. AGGREGATE IMPACTS FOR THE 1983-84 FISHING SEASON, DEVILS LAKE, NORTH DAKOTA

Impact	Angler Grouping				
	Local	Nonlocal	Nonresident (Scenario I)[a] Low Estimate	Nonlocal and Nonresident (Scenario II)[b]	All Anglers (Scenario III)[c] High Estimate
Expenditures	$2,484,342	$ 7,875,200	$1,747,640	$ 9,622,840	$12,107,182
Gross business volume	5,721,000	18,100,000	4,267,000	22,367,000	28,088,000
Personal income	1,275,000	4,067,000	1,041,000	5,108,000	6,383,000
Tax revenue	116,500	333,200	67,400	400,600	517,100
Employment	146	454	130	584	730

[a]Scenario I assumes only "new money" from nonresident anglers generates additional regional economic activity. The expenditure of locals and nonlocals are assumed to be merely displacements from other areas of the state.
[b]Scenario II assumes a regional perspective whereby expenditures of both nonresident and nonlocal anglers represent "new money" to the region.
[c]Scenario III assumes a regional perspective in that all fishing expenditures represent either pure exports or import substitutions. Therefore, all regional economic activity of anglers can be attributed to the fishery.

SOURCE: Schwinden and Leitch 1984.

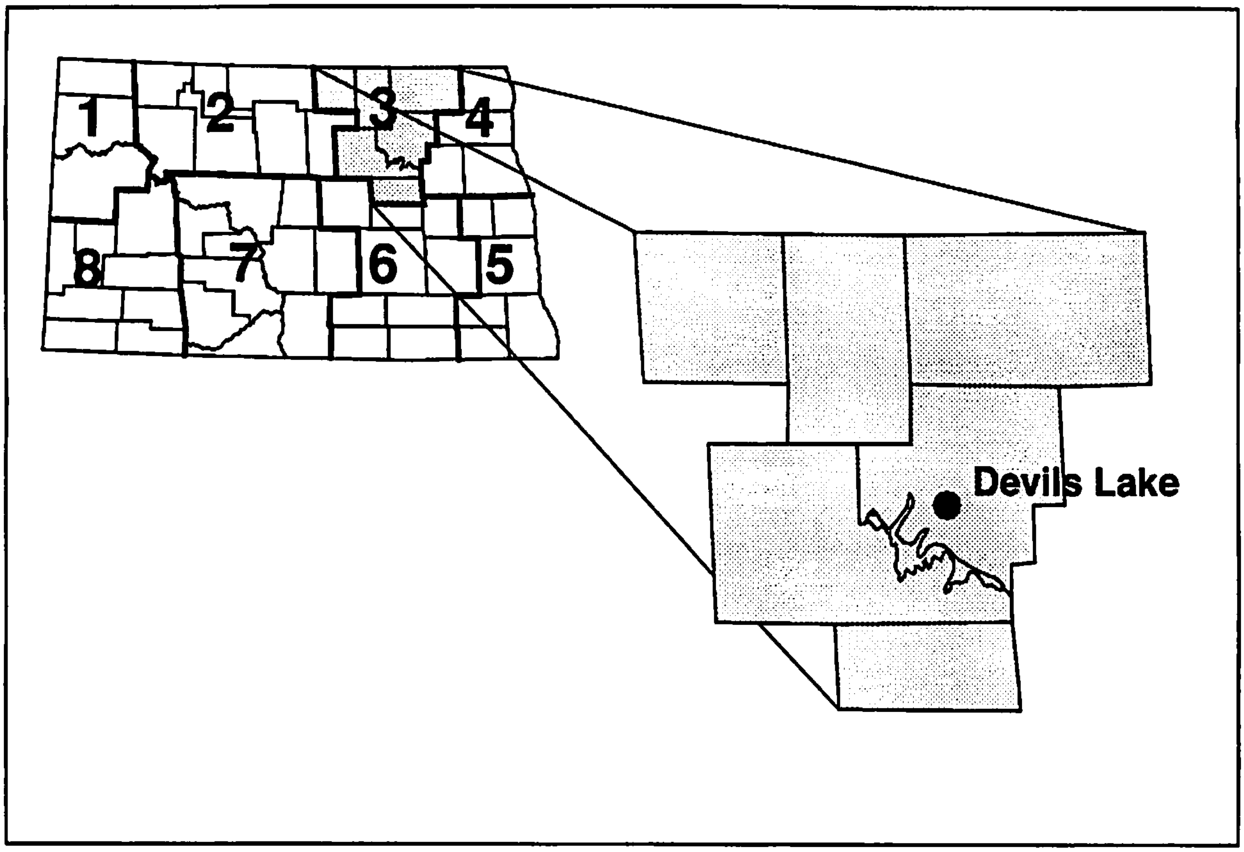


Figure 6. The Eight State Planning Regions in North Dakota

Average annual gross business volume in 1981-1985 was $1,614 million, with the largest single sector being households, followed by retail trade, ag crops, and ag processing (Coon and Leistritz 1987). While recreation and tourism are not included as separate sectors in North Dakota's input-output model, they likely account for the second greatest share of sales to final demand in this region.

Recreational Facilities

The Devils Lake region has many outdoor recreation areas (Appendix C), related to water-based recreation. A new state park has recently been authorized for Devils Lake (Figure 7). The main unit is centered on the existing facilities at Ziebach Pass. Satellite areas include the existing Highway 2 and East Bay facilities. A new facility will be created at Black Tiger Bay. Many public boat accesses are available around the lake (Figure 8).

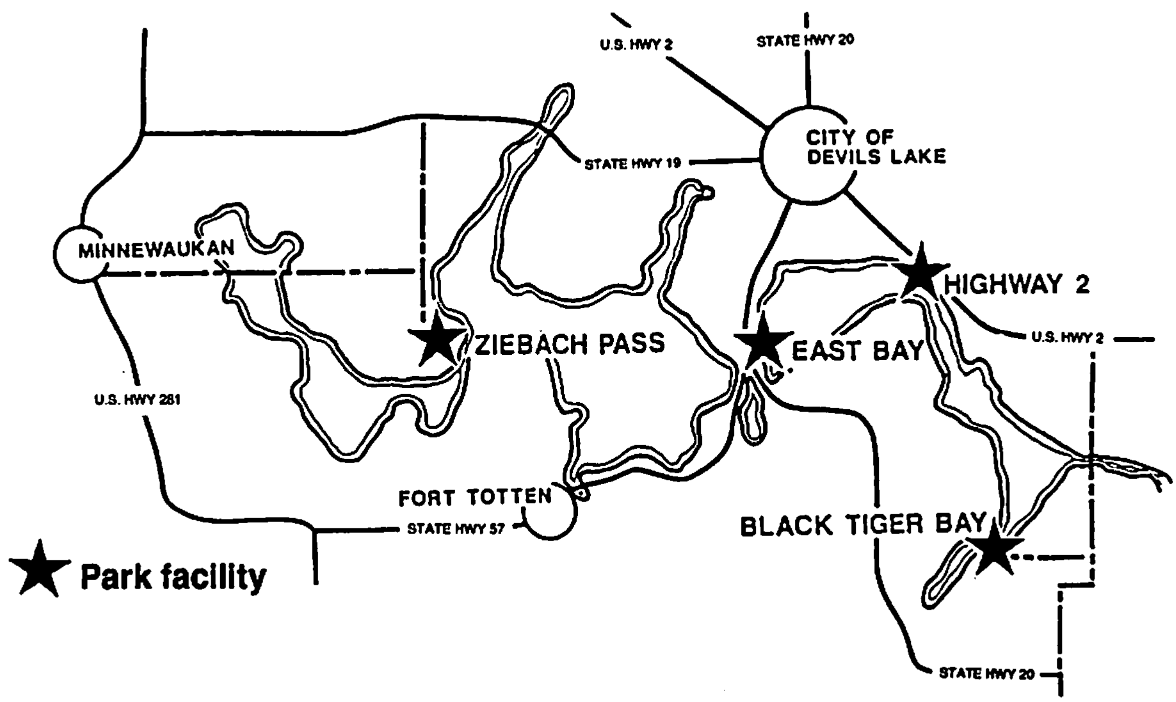


Figure 7. Location of New State Park Facilities at Devils Lake

SOURCE: Devils Lake State Park System Master Plan (1987).

The lake is known for its sportfishing, and a trade and service infrastructure has been established to serve that market. In addition, the region is in the central waterfowl flyway and attracts thousands of waterfowl hunters each fall.

The North Dakota State Comprehensive Outdoor Recreation Plan (SCORP) (1985) provides a general inventory of regional facilities by administrative agency and type of facility. In addition, SCORP provides an estimate of the total number of participation days by residents of the region in specific outdoor activities.

Expansion of the state park system was based upon the dispersal of facilities around the lake. The main element of the plan is the expansion of the existing Ziebach Pass Facility. Satellite areas are to include the existing Highway 2 recreation area, the existing East Bay Access site, and a new boat ramp and day-use area to be developed on Black Tiger Bay. Details of facilities, development plans, and estimated costs for each facility are given in the Devils Lake State Park System Master Plan (1987).

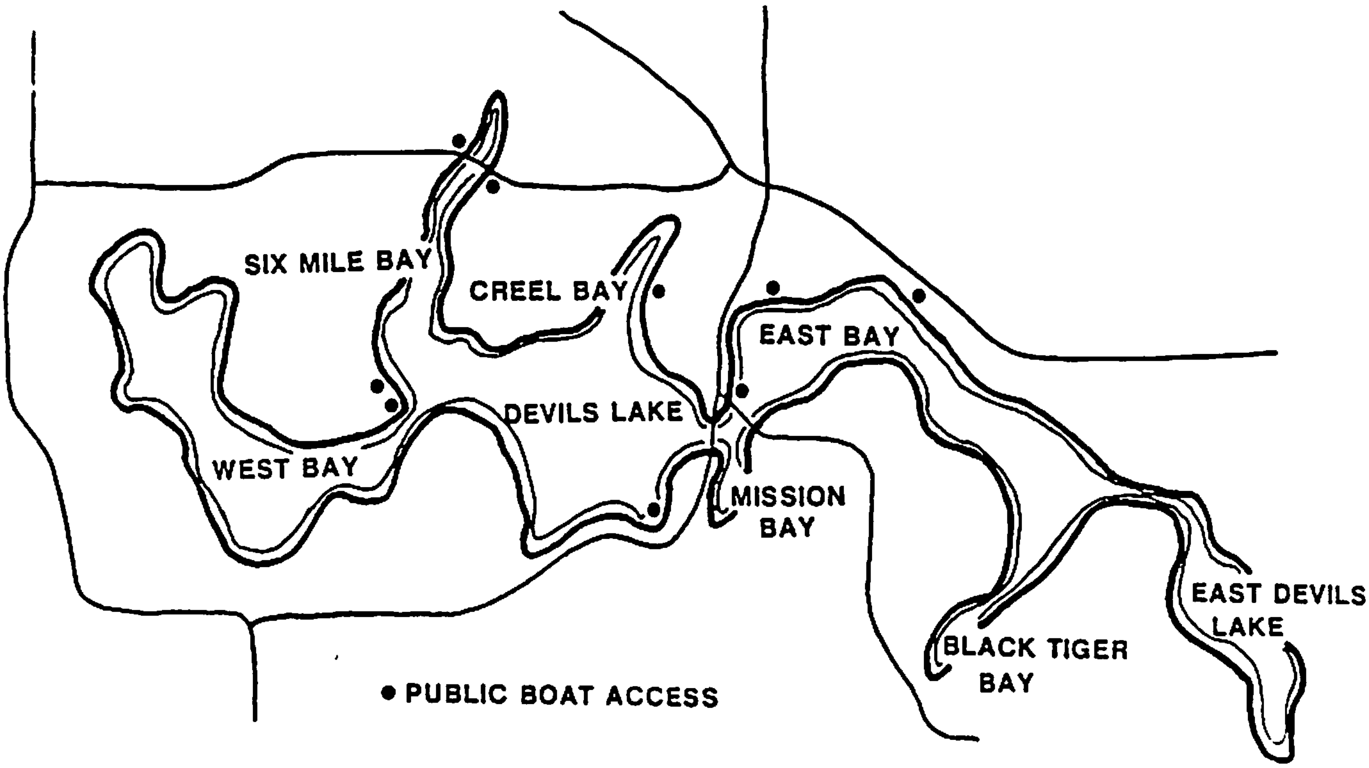


Figure 8. Public Boat Access to Devils Lake.

SOURCE: Devils Lake State Park System Master Plan (1987).

III. MANAGEMENT HISTORY

Very little active management for any purpose has ever been carried out for Devils Lake. Various resource management agencies have studied several basin problems including some attention to the lake itself. Most planning and proposed management has focused on the watershed in relation to flooding. While some agencies have been concerned with the lake and its potential as a resource, many constraints have prevented an active management role.

The primary physical constraint was addressed above--the effect of climate on a closed watershed. Institutional constraints are prevalent but more difficult to describe. Most important, however, may be the plethora of local general governments, state and federal agencies, tribal interests, and private interests. While the lake and its entire watershed are located in a single state, the autonomy of local governments and cross purposes of federal agencies combine to make development of a common management objective difficult and implementation even more so. Recent efforts to identify an outlet for the lake exemplify the institutional constraints to development of a management plan.

External Factors

The sociocultural history of the region has been studied and reported extensively. Management of the basin's resources is a more recent concern. Until the mid 1970s a regional approach to water resources management had not been attempted (Babcock 1952, Arnold 1920, Denoyer 1909, Devils Lake Basin Advisory Committee 1976). Following enactment in the 44th Legislative Assembly of the State of North Dakota, a Devils Lake Basin Advisory Committee was formed and charged with the responsibility of "developing a basin plan of water and related resource conservation and orderly development" (Devils Lake Basin Committee Study Report 1976).

Seventeen task forces were commissioned to study and make recommendations for the wise use of regional resources including Devils Lake. Flooding of agricultural lands in the upper watersheds was the primary concern at this time. However, management of wetlands and Devils Lake water quality were both related to the flooding issue. Recommendations for structural development in contributing subbasins were developed (Devils Lake Basin Committee Study Report 1976). The study also made recommendations of a management plan for Main Bay of Devils Lake as follows (p. xvii):

> The Devils Lake Task Force has detailed the following management plan for the main bay of Devils Lake and the Stump Lake chain. West Bay of Devils Lake (Minnewaukan Flats) will be managed and controlled as directed by the U.S. Fish and Wildlife Service under Garrison Diversion agreements. Devils Lake and East Bay Devils Lake will be controlled at elevation 1424 msl. This level would be maintained by supplemental flows from Garrison Diversion feeder canal. A control structure would be constructed in the area of Kirt's Road, Section 13, Township 152 North, Range 63 West. This structure would regulate the flows into East Devils Lake. East Devils Lake would be controlled at elevation 1421 msl, thereby making this bay the sump for the main lake. This plan also calls for structures under Highways 20 and 57 and the Burlington-Northern Railroad to pass boat traffic with the water at elevation 1424 msl. At present none of the existing structures can pass boat traffic and therefore new structures will be needed. There will also be a need to upgrade the roadway at Highway 19 because of increased lake levels and inflow from Channel "A" of the Starkweather Watershed. The roadway at Ziebach Pass has been in poor condition for a number of years and with the stabilized lake bottoms of 1424 msl, this roadway will need to be upgraded.
>
> Stump Lake will be fed by an independent feed canal for Garrison Diversion into Eastern Stump Lake. Western Stump Lake would then become the sump for Eastern Stump Lake. The elevation of these two bays will be set at the time Garrison Diversion supplies water to this portion of the lake.

Nonstructural measures recommended by the committee included:

- restoring and preserving wetlands to retain flood waters and to serve as nutrient traps in order to enhance water quality,

- establishing land treatment measures to reduce erosion, and

- developing floodplain zoning with enforcement capability.

Oversight responsibilities for the committee were vested in the State Water Commission. The North Dakota Water Commission (1983) published the State Water Plan with the purpose of assessing the long-term water requirement within North Dakota excluding federal and tribal water rights. The responsibility for implementing decisions contained in the plan is "in the political-legislative-private domain and rests ultimately with the people" (North Dakota Water Commission 1983, p. 4). Therefore the plan should be viewed as one part of an overall management program, which includes (1) a permit system, (2) project investigation and design, (3) project construction, (4) program administration, (5) operation and maintenance, (6) regulation and enforcement, (7) coordination, (8) data collection, and (9) research.

The major problem in the Devils Lake Basin defined by the State Water Plan is frequent overland sheet flooding of agricultural lands. Consequently, 212 miles of improved waterways were proposed. Additional problems include good quality rural drinking water and eutrophication of Devils Lake due to nutrient loss from agricultural runoff and wind erosion. In 1980 approximately 775,000 acres of cropland, 68,000 acres of pasture, 75,000 acres of rangeland, and 5,000 acres of forest were in need of land treatment such as strip-cropping, windbreaks, and grassed waterways.

Additional problems are associated with the rising lake level. Residences, businesses, roadways, and a municipal waste treatment plant have all been affected.

The State Water Commission's recommended plan for action is provided as Appendix D. The estimated cost in 1980 dollars was $44 million.

Agency Roles in Management

As noted above, the plethora of local general governments, special districts, state and federal agencies, and tribal and private interests have been a constraint to proactive management of the Lake. Local governments have been primarily interested in flood control and wastewater treatment; state government agencies in flood control, water quality, and recreation; federal agencies in water quality and waterfowl production; and many have been involved in shoreline and lake bottom ownership disputes. This divergence of purpose, oftentimes cross-purposes, has left little time and/or resources available for more than reactive management. What follows is a brief synopsis of the roles of government agencies in the management of Devils Lake.

U.S. Fish and Wildlife Service

The Devils Lake Wetland Management District (WMD), an arm of the U.S. Fish and Wildlife Service, is tasked with management and production of waterfowl. The district office in the City of Devils Lake was established in 1968 and manages lands in eight counties. Secondary objectives of the WMD are preservation of natural ecosystems, including native prairie flora, wetland complexes, and indigenous wildlife. The only active management structures operated by the WMD, which affect Devils Lake, are water control structures that regulate levels of the upstream chain of lakes located at Lake Alice and Lake Irwin.

The role of the U.S. Fish and Wildlife Service relative to the Devils Lake fishery has been to support the state's Game and Fish Department. Because the state does not have its own fish hatchery, it supplies eggs to the federal hatchery at Valley City. The federal hatchery provides equipment and personnel to harvest fish eggs from Devils Lake and raise them to term. State and federal fisheries personnel then mutually decide on the allocation of fry.

A third area in which the U.S. Fish and Wildlife asserts local management authority is at Sully's Hill National Game Preserve. This tract is managed for protection of small herds of bison and elk. Sully's Hill is a 1,674-acre preserve located on the south shore of Devils Lake in Benson County.

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers has traditionally been charged with maintaining the Nation's waterways and controlling and combating flooding. While Devils Lake is classified as a "navigable waterway" by the Corps--because of commercial navigation years ago--the Corps' presence has been mostly unnoticed until recently.

The Corps asserted permitting authority, under Section 404 of the Clean Water Act, when local water management districts wanted to construct Channel A that would empty into Devils Lake. More recently the Corps has been studying the feasibility of an outlet to the lake (U.S. Army Corps of Engineers 1988). The Corps also funded a biota study (Peterka 1986). Finally, the Corps has recently established a regulatory office in North Dakota to monitor dredge and fill activity as it pertains to Section 404.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency has only participated as an observer of water quality in the Basin. Most recently they have been actively involved in the outlet study. Their concern is for water quality in the Sheyenne River, the proposed receiving watercourse for Devils Lake water.

North Dakota Game and Fish Department

The state agency with responsibility for fish and wildlife resources is the Game and Fish Department (GFD). The role of the GFD in management of the lake as a fishery is important. Programs and plans are initiated, implemented, and evaluated by the department. The GFD began active involvement with the Devils Lake fishery when the lake began to refill following the drought of the 1930s. The lake, at that time, had high salinity. Nevertheless, it was stocked with northern pike fingerlings and later became a source of northern pike eggs.

The GFD is responsible for establishing and enforcing fishing seasons and limits. In order to carry out this role they conduct creel census and other research on the fishery. The GFD has funded four scientific research projects involving Devils Lake over the past ten years (Table 4).

TABLE 4. GAME AND FISH DEPARTMENT FUNDED RESEARCH PROJECTS

Number	Title	Researcher
F-2-R	The Effects of Salinity on Reproductive Success of Fishes in the Devils Lake Chain 1985 to Present	Dr. John Peterka NDSU
F-2-R	Gammarus Lacustris, Importance in Food Chain, 1986 to Present	Dr. John Peterka NDSU
F-2-R	Water Quality Literature Review and Planning for Monitoring Water Quality and Making Predictions, 1986	Dr. Elliot Shubert UND
F-2-R	Life History Data on Yellow Perch, 1983-1986	Dr. John Peterka NDSU

North Dakota Health Department

The Health Department is responsible for establishing water quality standards (see Water Quality section above). The department does not maintain a continuous monitoring network or system in the Basin. All water quality assessment has been conducted under contract by consultants for specific programs or research activities.

North Dakota Water Commission

The State Water Commission (SWC) is charged with the "conservation, management, development and control, of waters in this state, public or private, navigable or unnavigable, surface or subsurface ..." (ND Century Code 61-02-01). While they were instrumental in development of the Devils Lake Basin Study (Devils Lake Basin Advisory Committee 1976), their primary interest has been to manage the Basin to control flooding. They serve the dual role of regulator and project development. However, due to physical and financial resource constraints, the SWC has, like most of the other agencies, played a passive role in the management of the lake.

North Dakota Parks and Recreation Department

Development of a new state park on Devils Lake was discussed above. The Parks Department has been a key player in increased recreational access to the lake. Their function has, however, been as a user of the resource, rather than a manager for use.

UND Biological Station

The Biological Station was built during the 1890s. The building is leased to the State Game and Fish Department and is used as office space. There are no management or research functions currently associated with the Biological Station and Devils Lake.

Local and Regional Governments

Devils Lake lies in two counties, its basin in six. There are five cities on its shore: Devils Lake, Minnewaukan, Fort Totten, St. Michael, and Tokio. Several other special district governments overlap the lake's immediate basin. The North Central Planning Concil includes the entire lake in its planning region.

The local governments have long used the lake as a resource, but have also reacted to its rising waters and changing water quality. Some have tried to control their wastewater and runoff discharges into the lake, while others have used the lake as a discharge site. Like the many state and federal agencies, local governments have mostly reacted and have not actively managed the lake as a resource.

Tribal Government

Fort Totten Sioux Reservation has not conducted any active management during modern times. The State Supreme Court has held that ownership around Devils Lake fluctuates with the elevation of the water. The current boundary is about 1,426 feet msl. Therefore, ownership above 1,426 msl is vested with private property owners. However, all ownership issues concerning the lake bed have not been resolved. Presently the Devils Lake Sioux Tribe is suing to establish its ownership of the lake bed. The tribe is claiming the United States holds the lake bed in trust for them. The claim is based upon an interpretation of the treaty establishing the reservation. Presently the Court is considering a motion that would end the case by denying the tribe's claims. A decision is expected soon (Sand 1988).

IV. POTENTIAL COMMERCIAL USES OF DEVILS LAKE

While the range of potential economic development options for Devils Lake is only constrained by one's imagination, the number of economically viable options may be low.

Commercial Fishing. There may be limited potential for commercial fishing in the lake itself or for some form of aquaculture using the lake's resources. Peterka (1974) investigated the potential of growing trout in northern prairie potholes, and Anderson and Leitch (1985) looked into commercial aquaculture in the state.

Bird-Watching. Due to the increased national participation in bird-watching (VanHorne 1986, *Time* 1987, *New York Times* 1986), there may be a management scheme that includes commercializing bird-watching on and adjacent to Devils Lake.

V. RESOURCE SUMMARY

Physical

The physical resource is the lake, its waters and biota, and the shoreline. However, the lake's physical-chemical characteristics are the primary constraint to successful management; that is, water quality will be difficult if not impossible to manage, severly restricting the range of uses and the feasibility of long-term investment.

Personnel are available to implement almost any management plan for use of Devils Lake, and technical expertise exists to carry out any foreseeable management plan. The primary constraint to innovative management of Devils Lake is management or institutional constraints. The multiple jurisdictions and multiple-level jurisdictions with potential management influence over the lake's resources impose a serious constraint on unified management by a single entity or for a single purpose.

VI. CONCLUSION AND RECOMMENDATIONS

Devils Lake is currently a valuable natural resource, contributing a good deal of new wealth to the regional economy. However, the lake has a history of high and low water, with concomitant wide swings in water quality. Artificial manipulation of either water quality or water quantity may be physically feasible but would be expensive and perhaps met with resistance. Until questions regarding lake bottom ownership, tribal authority, and an outlet to the Sheyenne River are resolved, there is little utility in expansion of lake management plans. In the interim, further study of the potential of expanding recreational uses of the lake, may be worthwhile.

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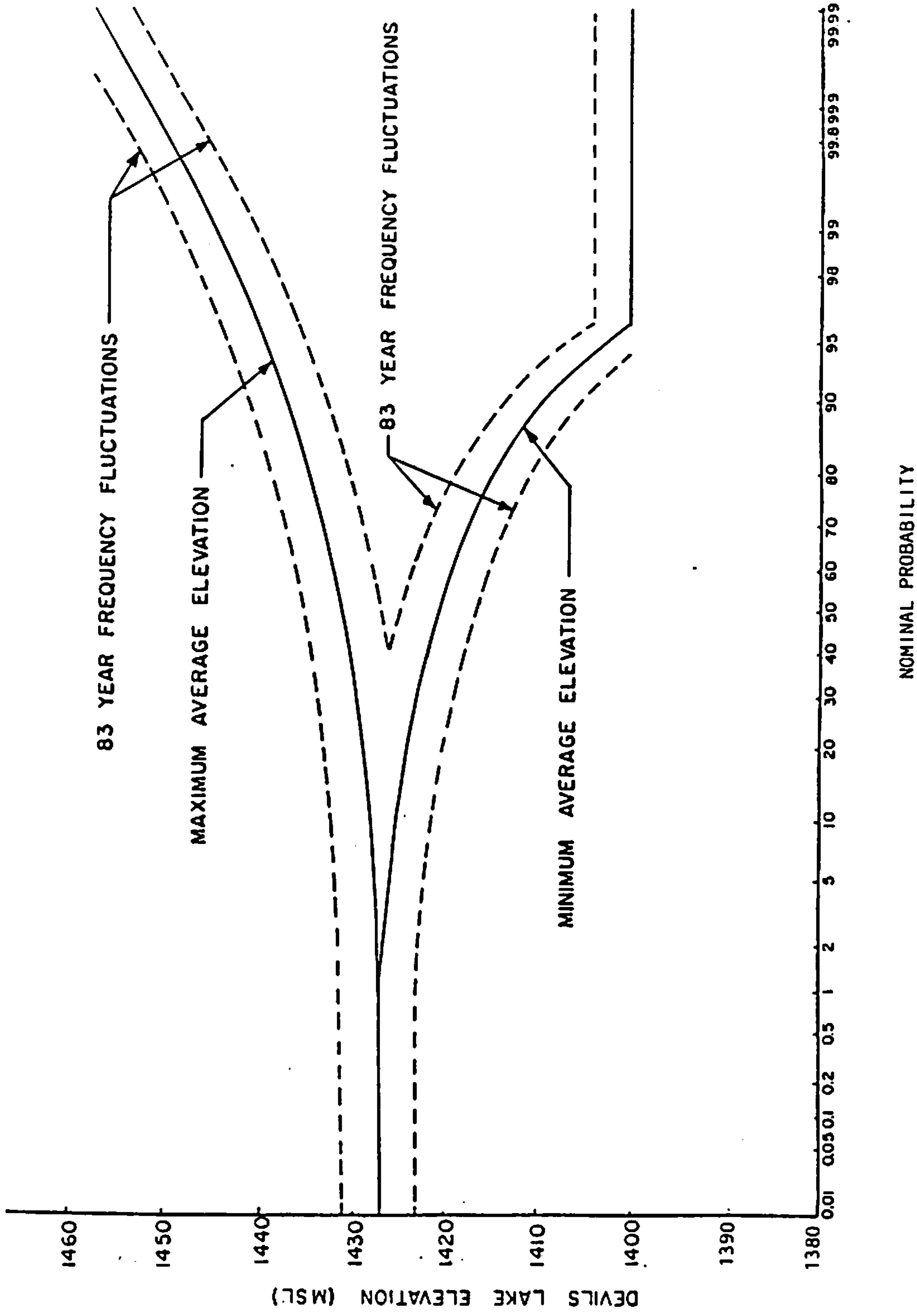
Appendix A

Lake Elevation Frequency Probabilities


83 YEAR FREQUENCY FLUCTUATIONS
MAXIMUM AVERAGE ELEVATION
83 YEAR FREQUENCY FLUCTUATIONS
MINIMUM AVERAGE ELEVATION
DEVILS LAKE ELEVATION (MSL)
1460
1450
1440
1430
1420
1410
1400
1390
1380
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8999 99.99
NOMINAL PROBABILITY

Appendix B

Total Dissolved Solids

APPENDIX TABLE 1. DEVILS LAKE CHAIN OF LAKES WATER QUALITY

Date	Devils Lake		East Bay Devils Lake		East Devils Lake		Western Stump Lake		Eastern Stump Lake	
	Elev.[1]	TDS[2]	Elev.[1]	TDS[2]	Elev.[1]	TDS[2]	Elev.[1]	TDS[2]	Elev.[1]	TDS[2]
Oct 64	1411.1	12,100			1398.9	81,700		21,300		119,000
Oct 65	1411.3	11,900			1399.6	54,600		6,530		105,000
Oct 66	1412.0	11,300			1401.1	47,900		5,940		91,600
Oct 67	1411.2	12,800			1399.8	61,600	1398.1	7,090	1384.5	95,600
Oct 68	1410.8	13,300			1400.8	64,000	1397.7	8,190	1384.2	103,000
Oct 69	1417.2	8,185			1399.3	56,200	1398.5	6,980	1384.0	107,000
Oct 70	1419.1	6,510			1400.1	57,300	1398.1	8,560	1384.1	112,000
Nov 71	1421.2	5,000			1400.6	48,200	1399.2	7,380	1380.7	71,600
Nov 72	1420.5	4,480			1400.4	45,000	1398.5	9,400	1384.5	80,700
Nov 73	1419.3	4,660	1414.4	8,580	1399.6	53,700	1397.6	11,200	1383.7	85,300
Dec 74	1422.9	3,370	1424.9	7,720	1401.6	51,400	1399.3	8,790	1384.4	79,400
Oct 75	1423.5	2,880	1425.4	7,010	1401.2	40,200	1398.9	9,300	1384.1	110,000
Oct 76	1423.1	2,850	1423.5	7,240	1404.1	29,100	1397.5	15,700	1382.9	143,000
Oct 77	1421.9	3,000	1427.3	7,810	1404.1	29,500	1397.3	25,100	1382.6	142,000
Oct 78	1422.3	3,080	1421.2	10,300	1403.9	30,500	1396.5	23,400	1382.2	149,000
Aug 79	1426.5	1,960	1426.4	5,110	1424.6	8,670	1398.4	7,530	1384.2	96,000
Nov 83		1,950		4,890		8,910				
Feb 84							1399.9	8,280	1384.9	94,500

1 Lake elevation (feet msl).
2 Total dissolved solids (mg/l).

SOURCE: U.S. Army Corps of Engineers. 1984. Devils Lake Basin, North Dakota Reconnaissance Report.

Appendix C

Regional Outdoor Recreation Areas

REGIONAL RECREATION AREAS

(C) County (M) Municipal (P) Private	Management	Acreage	Primitive Camping	Modern Camping	Boat Ramp	Boat Dock	Swimming Beach	Hiking Trails	Horseback Riding	Picnic Tables	Picnic Shelters	Horseshoe Courts	Playground	Comments
A. Balta Dam	M	110		X	X	X	X			X	X		X	Rodeo Grounds
B. Buffalo Lake	C	800	X		X	X	X			X	X		X	
C. Harvey Recreation Area	C	480			X	X	X			X	X		X	
D. Big Coulee Dam	C	236	X		X		X							
E. Snyder Lake Recreation Area	C	129	X			X	X						X	
F. Warsing Dam	C	83	X		X	X				X	X			
G. Wood Lake	C	120	X		X	X	X							
H. Juanita Lake	C	611	X		X	X		X	X	X		X	X	Canoeing, Bicycle Trail, Motorcycle Trail
I. Tolna Dam	C	200			X	X	X			X	X			
J. Red Willow Lake Resort	P	170	X	X	X	X	X	X	X	X			X	Canoeing
K. Old Settler's Park	C	164	X	X	X			X		X	X	X	X	Play Courts
L. McVille Dam	M	55	X		X	X	X			X	X			
M. Whitman Water-shed Dam	C	380	X		X	X	X							
N. Matigasbar Dam	C	180			X	X	X			X	X			

SOURCE: Devils Lake State Park System Master Plan 1987.