Hydrology of the Devils Lake Area, North Dakota

View of Devils Lake from Sully's Hill, September 1975. Photograph courtesy of North Dakota State Water Commission.

Front cover: Landsat satellite image of the Devils Lake area on May 26, 1986, taken at an altitude of 570 miles above the Earth's surface. Photograph courtesy of U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota.

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By Gregg J. Wiche, U.S. Geological Survey, and
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NORTH DAKOTA STATE WATER COMMISSION
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Bismarck, North Dakota
1994

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre-feet	0.001233	cubic hectometer
foot	0.3048	meter
inch	2.54	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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INTRODUCTION

About 5 percent of the landmass of North America drains into terminal lakes, which are lakes that are located at the lowest point within a closed drainage basin. Closed drainage basins have no outlet to the oceans. The advance and retreat of continental glaciers shaped the landscape of all of North Dakota east and north of the Missouri River. Thousands of closed drainage basins were formed in North Dakota as a result of the glaciation. Terminal lakes located in these closed drainage basins range in size from a few acres to more than 50,000 acres. Devils Lake Basin, in northeastern North Dakota, is a 3,810-square-mile closed drainage basin in the Red River of the North Basin (fig. 1). About 3,320 square miles of the total 3,810 square miles is tributary to Devils Lake; the remainder is tributary to Stump Lake.

The Devils Lake area has been a popular recreational area (figs. 2 and 3) for at least the last 110 years, and Devils Lake has been the main attraction for much of the recreation. Unlike most terminal lakes, Devils Lake has been a productive sport fishing lake intermittently since settlers arrived in the early 1880's. Steamboats, such as the Minnie H (fig. 4), carried cargo and passengers on Devils Lake from 1883 through 1909, and commercial fishing was conducted at Devils Lake in the 1880's. However, in 1888 a major fish kill greatly diminished the fishery of Devils Lake, and by 1905 the fishery had disappeared.

Recreational and fishery values of Devils Lake are closely associated with water-level fluctuations of the lake. In the late 1930's and early 1940's, various plans were developed by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation to divert water from the Missouri River to stabilize the water

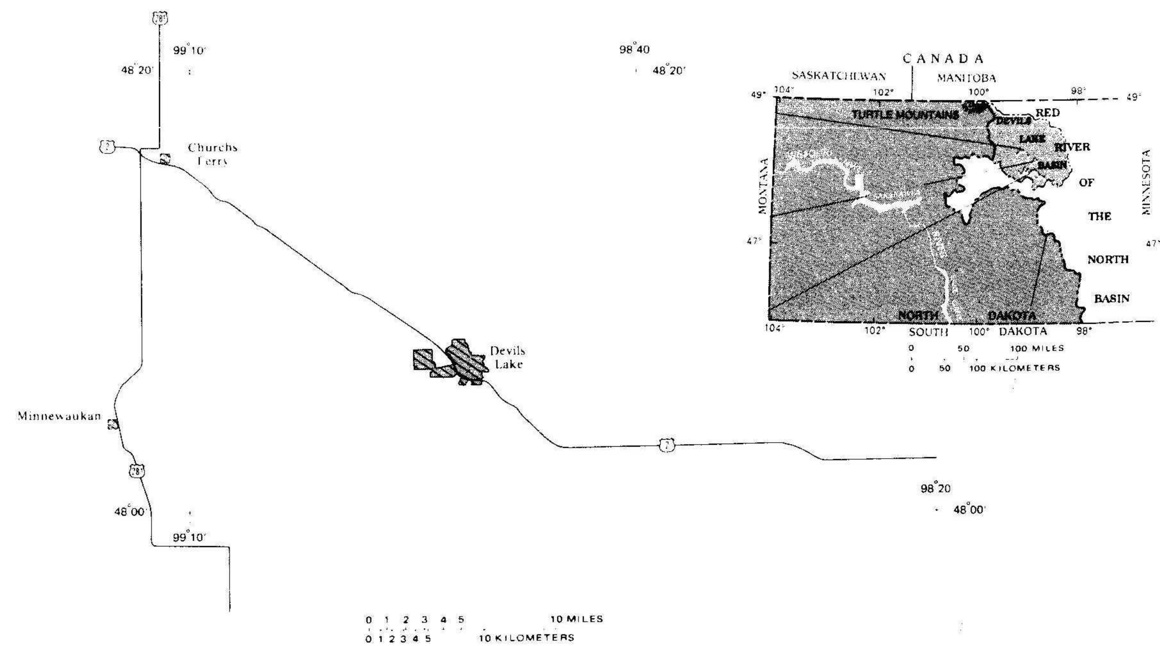

Figure 1. Location of Devils Lake and the chain of lakes in northeastern North Dakota.

Figure 2. Ski jumping at Sully's Hill on the south shore of Devils Lake, December 1936. (From State Historical Society of North Dakota.)

level to protect recreation at Devils Lake; however, no lake stabilization plans were implemented. Rising water levels from about 1969 through 1987 resulted in an increase in recreational activity (especially fishing) and tourism, but declining water levels from 1987 to 1991 provided the impetus for local organizations and State and Federal agencies to identify options that could be used to stabilize the water level of Devils Lake to maintain and enhance the growing tourist industry.

From 1986 through 1988, the U.S. Geological Survey and the North Dakota State Water Commission conducted a cooperative study of the hydrologic components that affect the water balance of Devils Lake. The U.S. Geological Survey studied the energy balance and evaporation of Devils Lake (Wiche, 1992), and the North Dakota State Water Commission studied the ground-water movement into and out of Devils Lake (Pusc, 1993).

The purpose of this report is to describe the hydrology of the Devils Lake Basin and, in particular, the Devils Lake area. The report is not intended to be a comprehensive technical reference; rather, it is written for individuals who want a basic understanding of how hydrologic processes affect the Devils Lake area. References are given for those who desire more information about the hydrology of the Devils Lake Basin.

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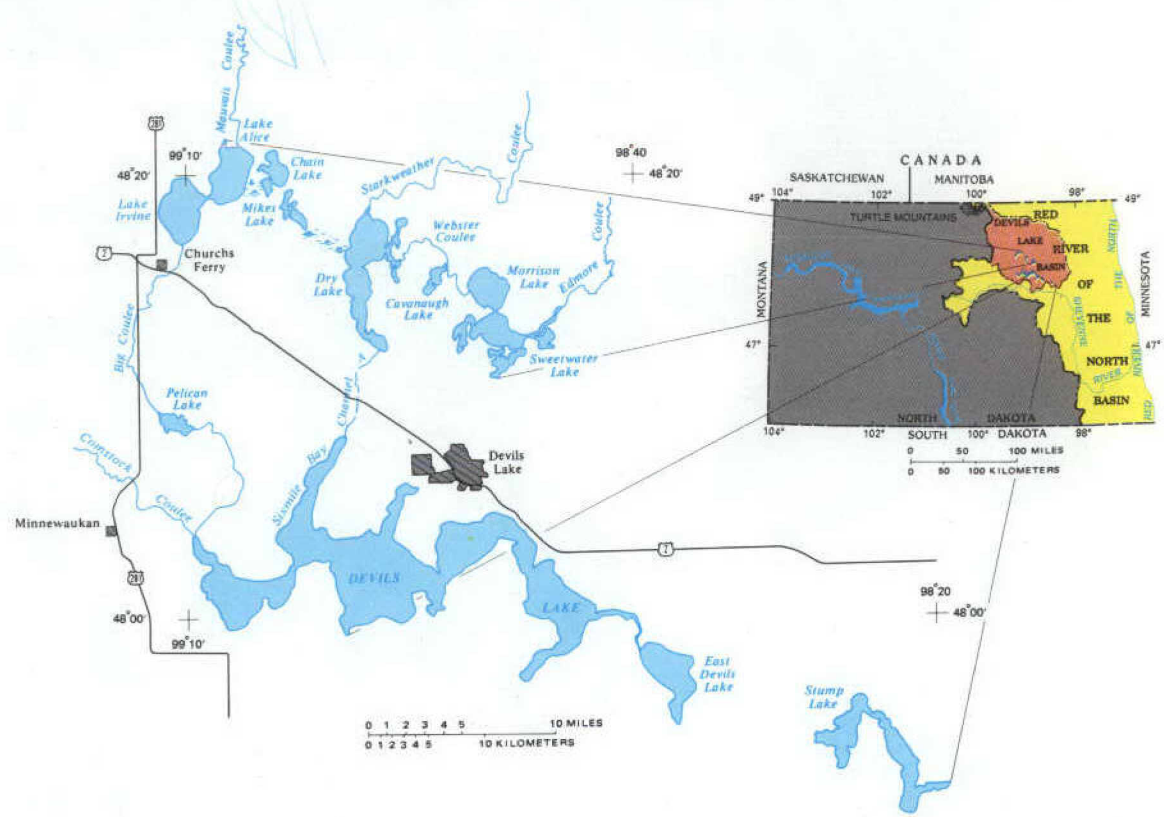


Figure 1. Location of Devils Lake and the chain of lakes in northeastern North Dakota.

DESCRIPTION OF STUDY AREA

Geologic Setting

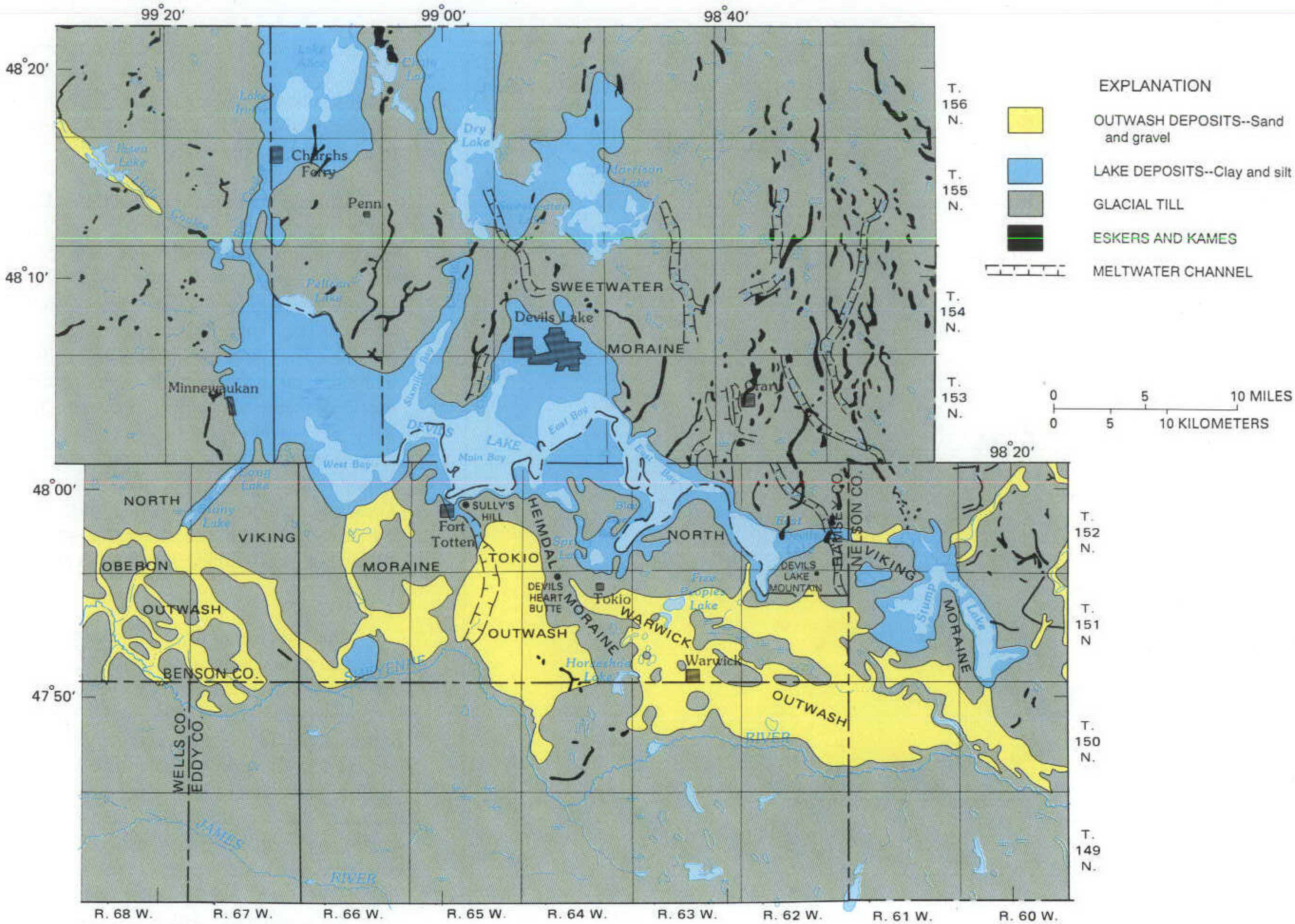
Geologic features of the Devils Lake Basin primarily are a result of the depositional and erosional effects of continental glaciation, which ended about 10,000 years ago (Aronow, 1957; Bluemle, 1981). Glacial deposits include outwash deposits, lake deposits, and glacial till; glacial landforms include ground and end moraines, eskers, and kames (fig. 5). Glacial sediments range in size from microscopic clay particles to large cobbles and boulders. These sediments were deposited either as stratified layers of clay, silt, sand, and gravel (outwash and lake deposits) or as poorly sorted mixtures of variously sized material (glacial till). Lake deposits and glacial till mantle the land surface over much of the area around Devils Lake (fig. 5) as well as most of the Devils Lake Basin. Pierre Shale underlies the glacial sediments in most of the Devils Lake area.

The landscape of the Devils Lake Basin was much different before glaciation than it is today. Black shale of the Pierre Shale constituted the land surface. Preglacial rivers, such as the ancient Cannonball River (fig. 6), carved deep valleys into the shale. As glaciation occurred, preglacial rivers were dammed at ice fronts to form lakes. Overflow from these lakes carved diversion channels that subsequently were filled with outwash material (typically sand and gravel). Preglacial valleys and diversion channels were formed at different times and cross one another in a complicated manner that makes the subsurface geology complex (Hobbs and Bluemle, 1987). Subsequent glacial advances and retreats across the Devils Lake Basin deposited several layers of glacial sediments that buried the preglacial valleys and diversion channels. Hobbs and Bluemle (1987) stated that "in North Dakota, more than four major glacial events occurred."

Scouring and thrusting as the glaciers advanced and retreated also helped shape the surface of the Pierre Shale. In some areas of the Devils Lake Basin, the glaciers gouged out large depressions in the shale. In other areas, such as at Devils Lake, large blocks of shale were detached from their original site of deposition and redeposited in the glacial drift. As the glaciers advanced, they overrode the saturated sediments that had filled the Cannonball River Valley (figs. 7a and 7b). The weight of the advancing glaciers increased ground-water pressure in the Cannonball River Valley sediments, the overlying material was lifted up into the advancing glacier (fig. 7c), and an excavated depression was created (fig. 7d). The glaciers then pushed or thrust the material a few miles to the south-southwest (fig. 7d).

Figure 3. Waterfowl hunters in the Devils Lake area in the early 1900's. (From Devils Lake Chamber of Commerce.)

Figure 4. The Minnie H at Devils Lake in the late 1800's. (From State Historical Society of North Dakota.)



Base from U.S. Geological Survey
State base map, 1963

Figure 5. Generalized surficial geology of the Devils Lake area. (Modified from Paulson, 1964; Bluemle, 1965, 1973; Carlson and Freers, 1975; Clayton and others, 1980a, 1980b; Hobbs and Bluemle, 1987.)

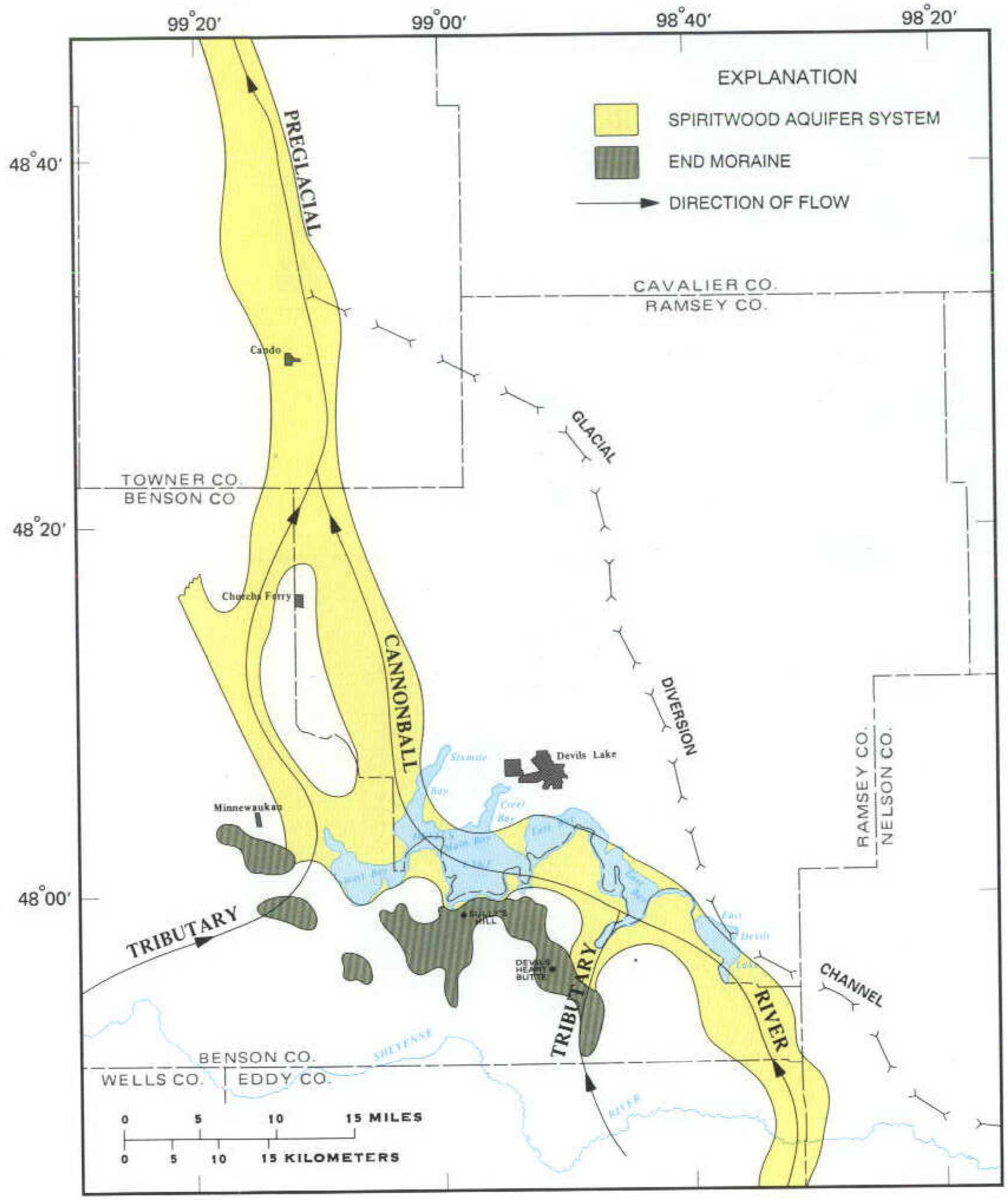


Figure 6. Preglacial drainage and the extent of the Spiritwood aquifer system in the Devils Lake area. (Modified from Hobbs and Bluemle, 1987.)

The excavated depression now is occupied by Devils Lake, and the material thrust to the south-southwest is known as Sully's Hill (Bluemle, 1981; J.P. Bluemle, written commun., 1991; fig. 7d).

Although the earth beneath the Devils Lake area is saturated with water below certain depths, some sediments, such as sand and gravel deposited in the preglacial valleys and diversion channels, yield larger quantities of water than other sediments, such as clay or silt. The sediments that yield sufficient quantities of water to wells or springs to be useful are termed aquifers (Paulson, 1983). Sand and gravel deposits in preglacial valleys and diversion channels constitute the major buried-valley aquifers in the area (fig. 8). Outwash materials (fig. 5) deposited during the last glacial advance and retreat comprise the major near-surface aquifers in the area (fig. 8).

Aquifers generally are described as confined or unconfined. A confined aquifer is overlain and underlain by beds of less permeable material. The water within a confined aquifer is under pressure. If a well is drilled into the aquifer, water will rise in the well to some level higher than the top of the aquifer. The water levels in a number of such wells define an imaginary surface known as the potentiometric surface. An unconfined aquifer is not overlain by beds of less permeable material. The water surface in an unconfined aquifer is referred to as the water table. In wells completed in unconfined aquifers, the water will rise only to the level of the water table.

Sand and gravel deposited in the valley of the ancient Cannonball River is termed the Spiritwood aquifer system (fig. 6). The Spiritwood aquifer system in North Dakota is an extensive buried-valley aquifer that trends in a southeasterly direction from the Canadian border in Towner County to the South Dakota border (North Dakota State Water Commission, 1986). In the Devils Lake area, the Spiritwood aquifer system as outlined by Hobbs and Bluemle (1987; fig. 6) is about 1 to 10 miles wide and 30 to 300 feet thick. About 100 to 200 feet of lake deposits and glacial till overlies and confines the Spiritwood aquifer system. The lake deposits and till have minimal permeability and, thus, do not yield water to wells rapidly enough to be of practical use for water supplies. Test drilling indicates that the Spiritwood aquifer system underlies Devils Lake and East Devils Lake (fig. 8). Southeast of Devils Lake, the Spiritwood aquifer system underlies the Sheyenne River Valley (fig. 8). Water levels in wells completed in the Spiritwood aquifer system vary from 150 feet below land surface on top of Devils Lake Mountain to several feet above land surface near Devils Lake. About 1 million acre-feet of ground water is stored in the Spiritwood aquifer system in the Devils Lake area (Trapp, 1968; Downey, 1973; Randich, 1977; Hutchinson and Klausing, 1980). By comparison, Devils Lake contains about 675,000 acre-feet of water when the lake is at an elevation of 1,425 feet above sea level.

Other aquifers in the Devils Lake area include the Starkweather aquifer, the McVille aquifer, the Warwick aquifer, the Tokio aquifer, and the Sheyenne River aquifer (fig. 8). A total of more than 1 million acre-feet of ground water is stored in all of these aquifers (Trapp, 1968; Downey, 1973; Randich, 1977; Hutchinson and Klausing, 1980).

Surface Drainage

The eastern, western, and northern boundaries of the Devils Lake Basin are poorly defined low divides. The southern boundary is made up of a series of recessional moraines that lie between Devils Lake and the Sheyenne River. Major subbasins within the Devils Lake Basin and principal streams draining the subbasins are shown in figure 9. Edmore, Starkweather, and Calio Coulees originate in southern Cavalier County and flow in a south-southwesterly direction. Mauvais Coulee originates along the southern flanks of the Turtle Mountains (fig. 1) 300 to 400 feet above the elevation of Devils Lake and generally flows in a southerly direction. Little Coulee originates in southern Rolette County and flows in a south-southeasterly direction.

Before 1979, streamflow from the principal streams flowed into the interconnected chain of lakes (Sweetwater Lake, Morrison Lake, Dry Lake, Mikes Lake, Chain Lake, Lake Alice, and Lake Irvine), and all streamflow from the chain of lakes flowed downstream through Big Coulee into Devils Lake (fig. 9). In 1979, the Ramsey County and Cavalier County Water Management Boards constructed Channel A, which connects Dry Lake to Sixmile Bay on Devils Lake (fig. 9). A levee also was constructed across the natural outlet of Dry Lake in 1979. The construction of Channel A and the levee on Dry Lake modified the drainage pattern in the basin. Discharge from Dry Lake to Sixmile Bay via Channel A is regulated by an adjustable head gate control at the south shore of the lake. Runoff into Sweetwater, Morrison, and Dry Lakes discharges through Channel A into Devils Lake; the remaining runoff discharges along the natural watercourse through Big Coulee into Devils Lake. A small quantity of runoff also enters Devils Lake by overland flow from drainage areas adjacent to the lake.

Edmore Coulee is the principal tributary to Sweetwater and Morrison Lakes. After Sweetwater and Morrison Lakes fill to the outlet elevation of about 1,458.5 feet above sea level, water flows into Dry Lake via Webster Coulee. Webster Coulee and Starkweather Coulee are the principal tributaries to Dry Lake. The outlet elevation for the gate control that regulates the water level of Dry Lake is set at 1,445 feet above sea level for October through April and at 1,447.5 feet above sea level for May through September.

Chain Lake receives inflow from Mikes Lake and Calio Coulee. When Chain Lake reaches an elevation of 1,440.8 feet above sea level, it spills into Lake Alice. Lake Alice also receives inflow from Mauvais Coulee. A channel connects Lake Alice to Lake Irvine, which has an outlet to Big Coulee at an elevation of about 1,436.6 feet above sea level.

HYDROLOGY OF DEVILS LAKE AREA

Prehistoric Water-Level Fluctuations

Since glaciation, the water level of Devils Lake has fluctuated from about 1,454 feet above sea level, the natural spill elevation of the lake, to about 1,400 feet above sea level (Aronow, 1957). According to Bluemle (1981), the elevation of Devils Lake was more than 1,440 feet above sea level 8,500 years before present. Callender (1968, p. 261) made various chemical analyses of sediment samples from Devils Lake to provide a lake-level chronology for the past 6,500 years. Callender (1968) concluded that

> "The lake was dry during the last part of the Hypsithermal (6,500 years before present) interval. The level rose and then declined several times between 6,000 and 2,500 years before present, after which a peat was deposited in Creel Bay approximately 1,340 years ago. Several more lake-level fluctuations culminated in a very saline, low-water stage 500 years before present, when oak trees grew on the dry surface sediment of East Stump Lake. The level subsequently rose until 1800 A.D., declined to a low-water stage in 1940 A.D., rose until 1951 A.D., and steadily declined from that time to the present [1968]. Comparison of the Devils Lake chronology with those from other regions indicates that major climatic changes which caused significant fluctuations in the lake level may have extended beyond the northern Great Plains region."

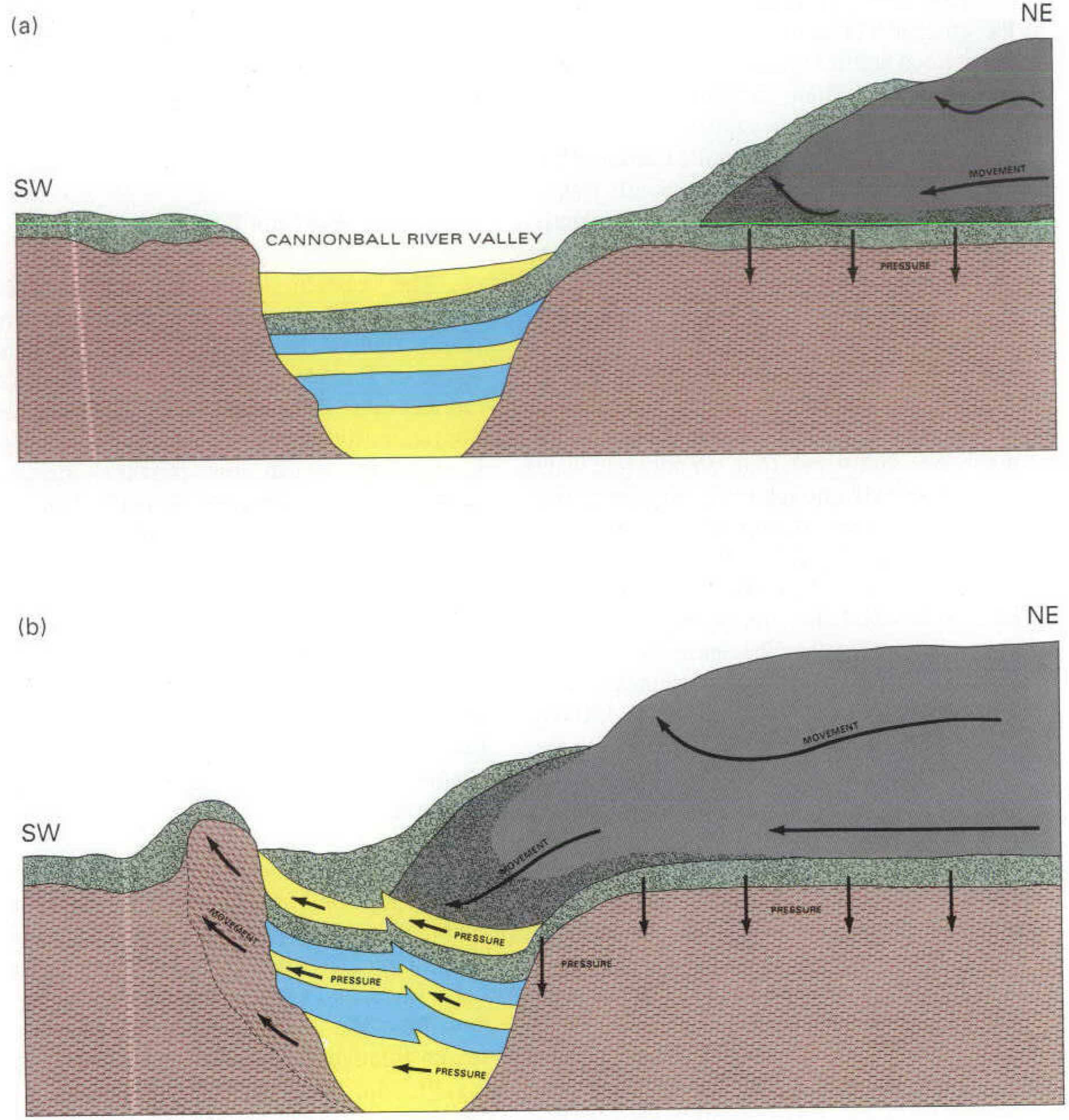
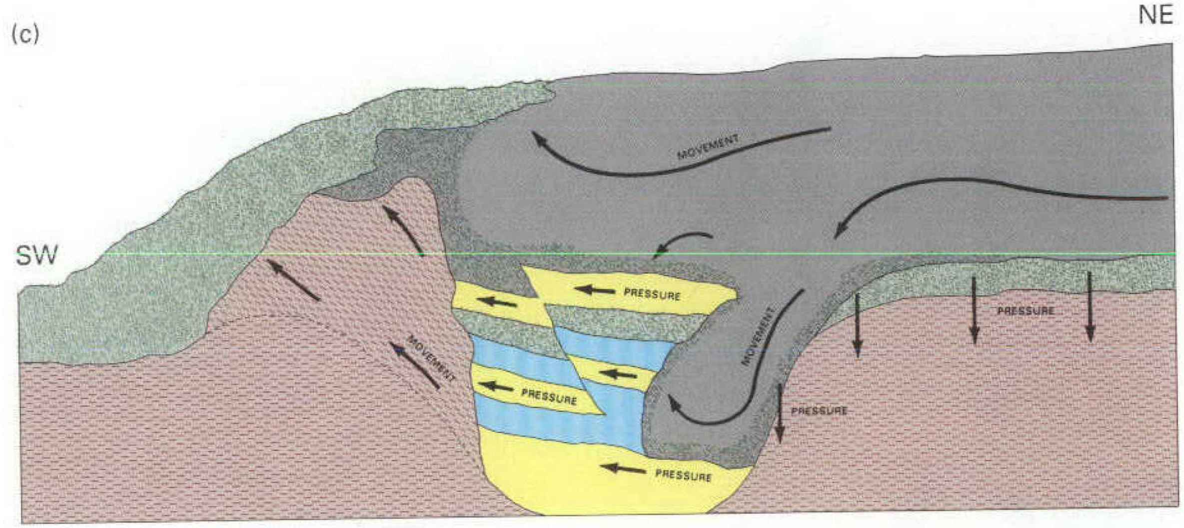
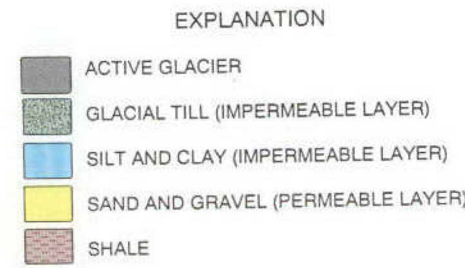


Figure 7. Formation of Devils Lake. (From J.P. Bluemle, written commun., 1991.)





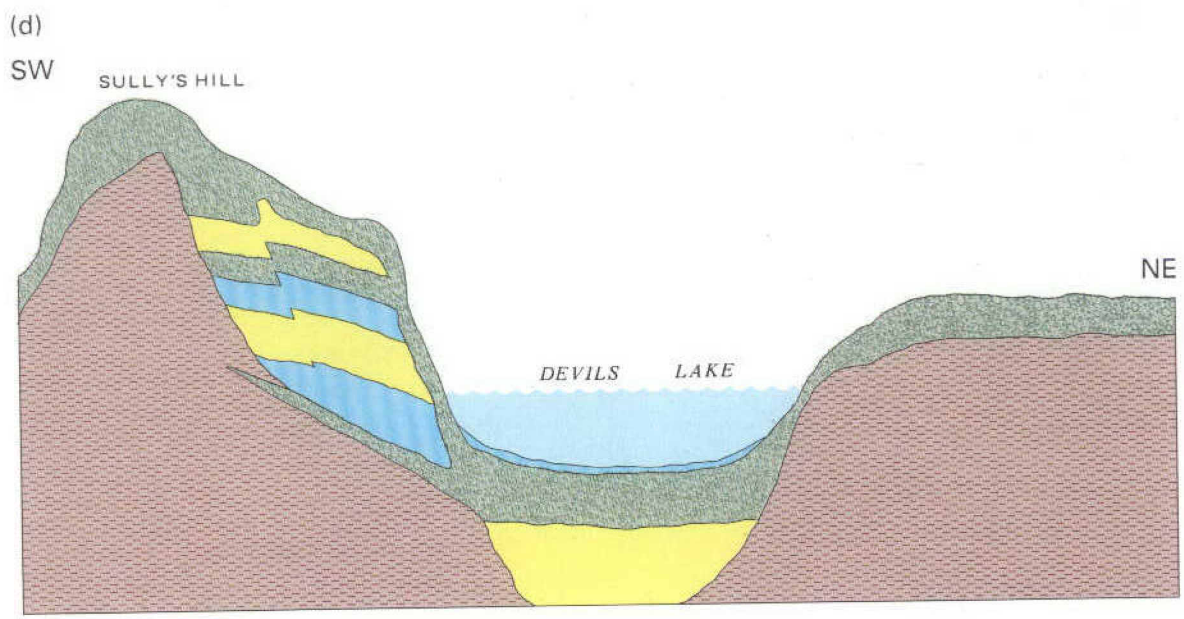
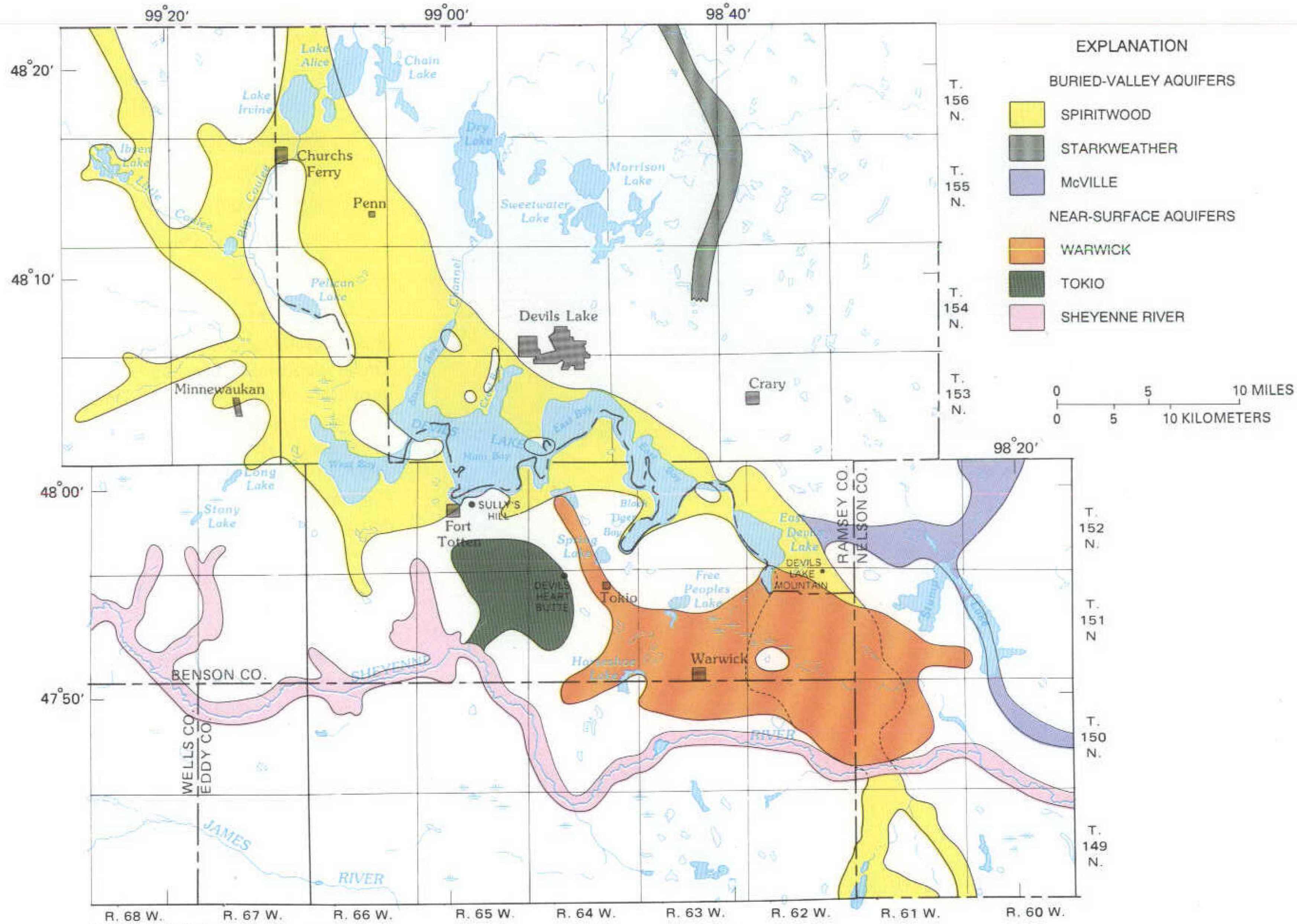


Figure 7. Formation of Devils Lake. (From J.P. Bluemle, written commun., 1991.)--Continued.

Aronow (1955, 1957) analyzed abandoned shorelines, water-deposited sand and gravel deposits containing buried soils and vertebrate remains, and rooted stumps uncovered by receding water around Stump Lake. In general, Aronow's interpretation (1955, 1957) of water-level fluctuations is similar to Callender's (1968), although some differences do exist. Aronow (1955, 1957) indicated that a lowering of water levels of lakes in the Devils Lake Basin occurred during a dry period in the 15th and 16th centuries, as evidenced by the growth of burr oak in Stump Lake. According to Brooks (1951), this dry period occurred throughout most of western North America. Following this dry period, there was a general rise in water levels from the mid-1500's until the mid- to late 1800's. This period of rising water levels commonly is referred to as the Little Ice Age. In a more recent study, Bluemle (1988) used radiocarbon dates of soils and concluded that Devils Lake overflowed into Stump Lake in the last 1,800 years.

In summary, all of these studies indicate that large and frequent water-level fluctuations of 20 to 40 feet occur every few hundred



Base from U.S. Geological Survey
State base map, 1963

Figure 8. Major glacial aquifers in the Devils Lake area. (Modified from Trapp, 1968; Downey, 1973; Randich, 1977; Hutchinson and Klausing, 1980; North Dakota State Water Commission, 1986; Pusc, 1993.)

Figure 9. Major subbasins in the Devils Lake Basin.

years. A rising or declining water level seems to be a more normal condition for Devils Lake than a stable water level.

Historic Water-Level Fluctuations

No documented records of water levels are available before 1867. However, Upham (1895, p. 595) indicated that the water level of Devils Lake was 1,441 feet above sea level in 1830. He based this water level on a large, dense stand of timber that grew at and above 1,441 feet above sea level. Below 1,441 feet above sea level, only scattered trees and brush existed. Captain H.H. Heerman informed Upham that, based on tree-ring chronology, the largest tree cut below 1,441 feet above sea level was 57 years old in 1887. Thus, Upham (1895, p. 595) concluded that in 1830 (57 years before 1887) the water level of Devils Lake was 1,441 feet above sea level.

Water levels of Devils Lake were recorded sporadically from 1867 to 1901 (fig. 10) when the U.S. Geological Survey established a gage at Devils Lake. For the period of record at Devils Lake, the maximum water level occurred in 1867; the water level was 1,438 feet above sea level and the lake had a surface area of about 140 square miles. From 1867 to 1940, the water level of Devils Lake declined almost continuously until it reached a recorded low of 1,400.9 feet above sea level and the lake was a shallow brackish body of water that had a surface area of about 10.2 square miles. From 1940 to 1956, the water level generally rose. From 1956 to 1968, the water level generally declined.

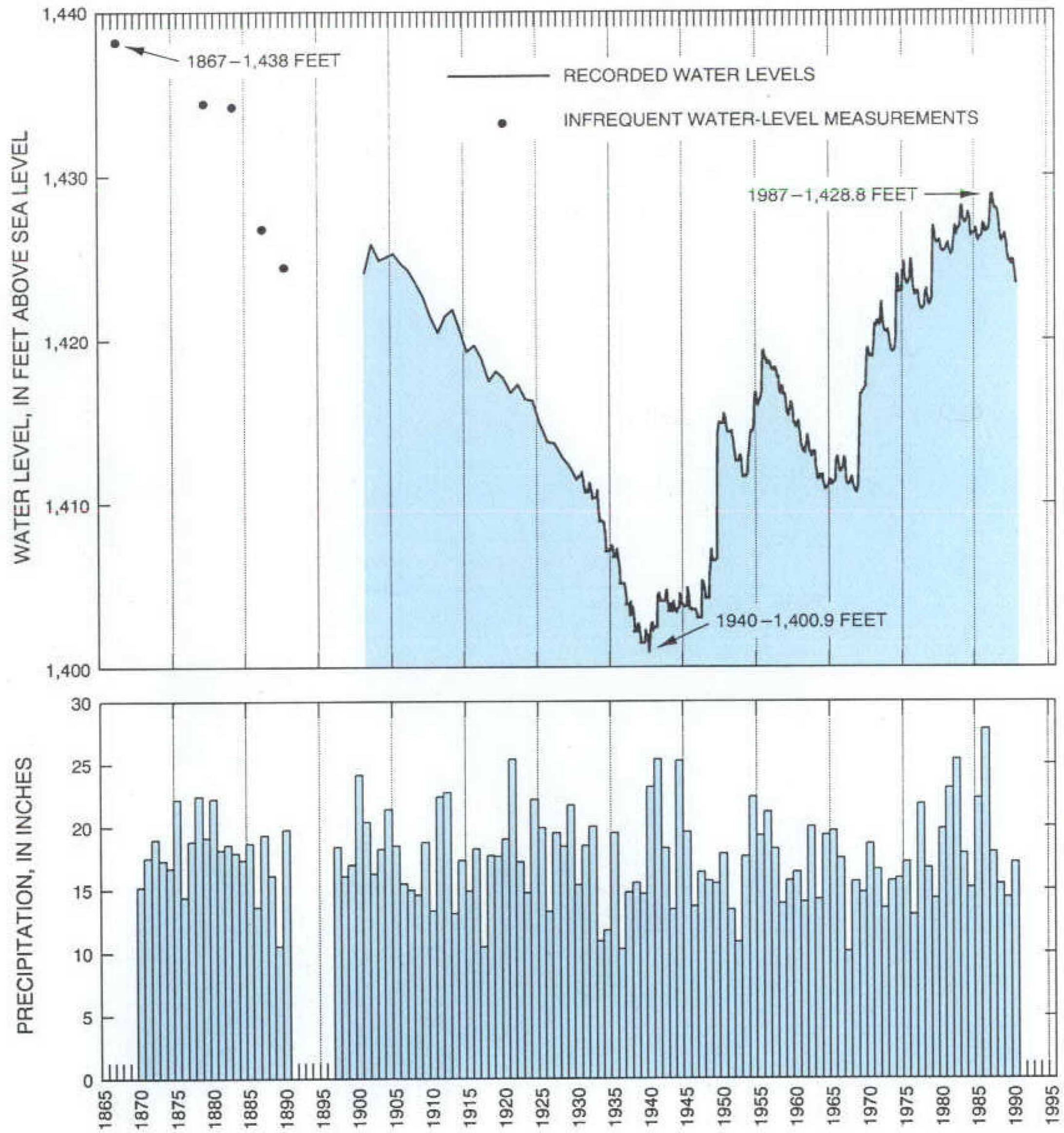


Figure 10. Historic water level for Devils Lake, 1867-1990, and annual precipitation, 1870-90, Fort Totten, and 1897-1990, city of Devils Lake.

From 1968 to 1987, the water level generally rose until it reached a peak of 1,428.8 feet above sea level, which is the highest water level in almost 100 years. At the peak in 1987, Devils Lake had a surface area of about 94 square miles. From 1987 to 1991, the water level of Devils Lake declined rapidly to 1,423.5 feet above sea level.

Ground-Water Flow Systems

Shallow Ground Water

Shallow ground water in the Devils Lake area occurs mainly in lake deposits and glacial till. A detailed examination of all available ground-water data indicates that the shallow ground water moves along various routes at differing velocities. Shallow ground water in the lake deposits and glacial till moves slowly (less than 0.01 inch per year) toward the many potholes and lakes throughout the basin (fig. 11). A large percentage of this ground water never reaches Devils Lake. Instead, most of the shallow ground water in the lake deposits and glacial till is returned to the atmosphere as transpiration by plants or evaporation from potholes. Shallow ground water in the lake deposits and glacial till interacts with Devils Lake only in the area immediately surrounding Devils Lake (figs. 5 and 11).

Deep Ground Water

On the highlands away from Devils Lake, ground water that is not returned to the atmosphere by transpiration or evaporation moves slowly downward through the lake deposits and glacial till and into the Spiritwood aquifer system (fig. 11). Water in the Spiritwood aquifer system moves slowly toward Devils Lake, Lake Irvine, or the Sheyenne River (fig. 12). Ground-water flow velocities in the Spiritwood aquifer system range from 1 to 12 inches per year (Pusc, 1993). Near Devils Lake, ground water moves slowly upward from the Spiritwood aquifer system through the overlying lake deposits, glacial till, and lake sediments into Devils Lake (fig. 11). During years of high runoff, when Devils Lake rises, the water level in the Spiritwood aquifer system in the Devils Lake area also rises (fig. 13). Conversely, when Devils Lake declines, the water level in the Spiritwood aquifer system declines. Water-level fluctuations in the Spiritwood aquifer system are a combined result of: (1) Water-level fluctuations in the regional discharge area (Devils Lake), (2) recharge from precipitation, and (3) the increase or decrease in weight that a changing lake level applies to the confined Spiritwood aquifer

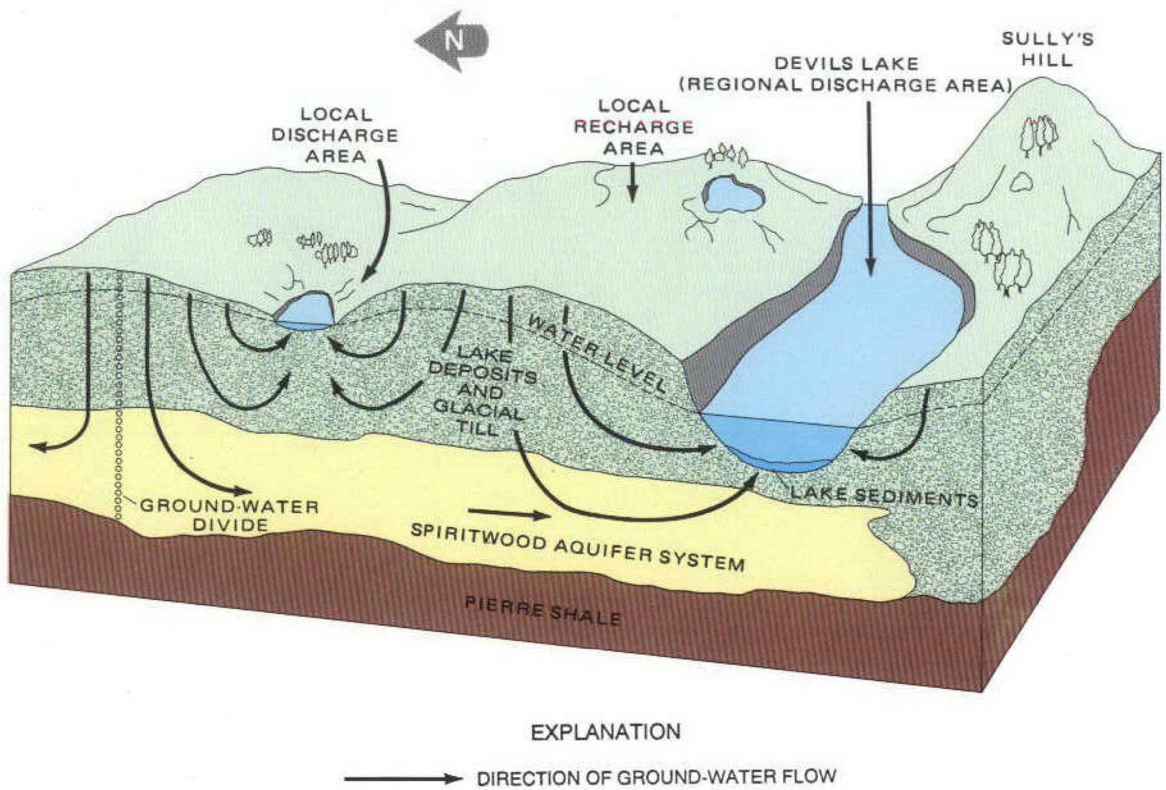


Figure 11. Ground-water flow system in the Devils Lake area. (From Pusc, 1993.)

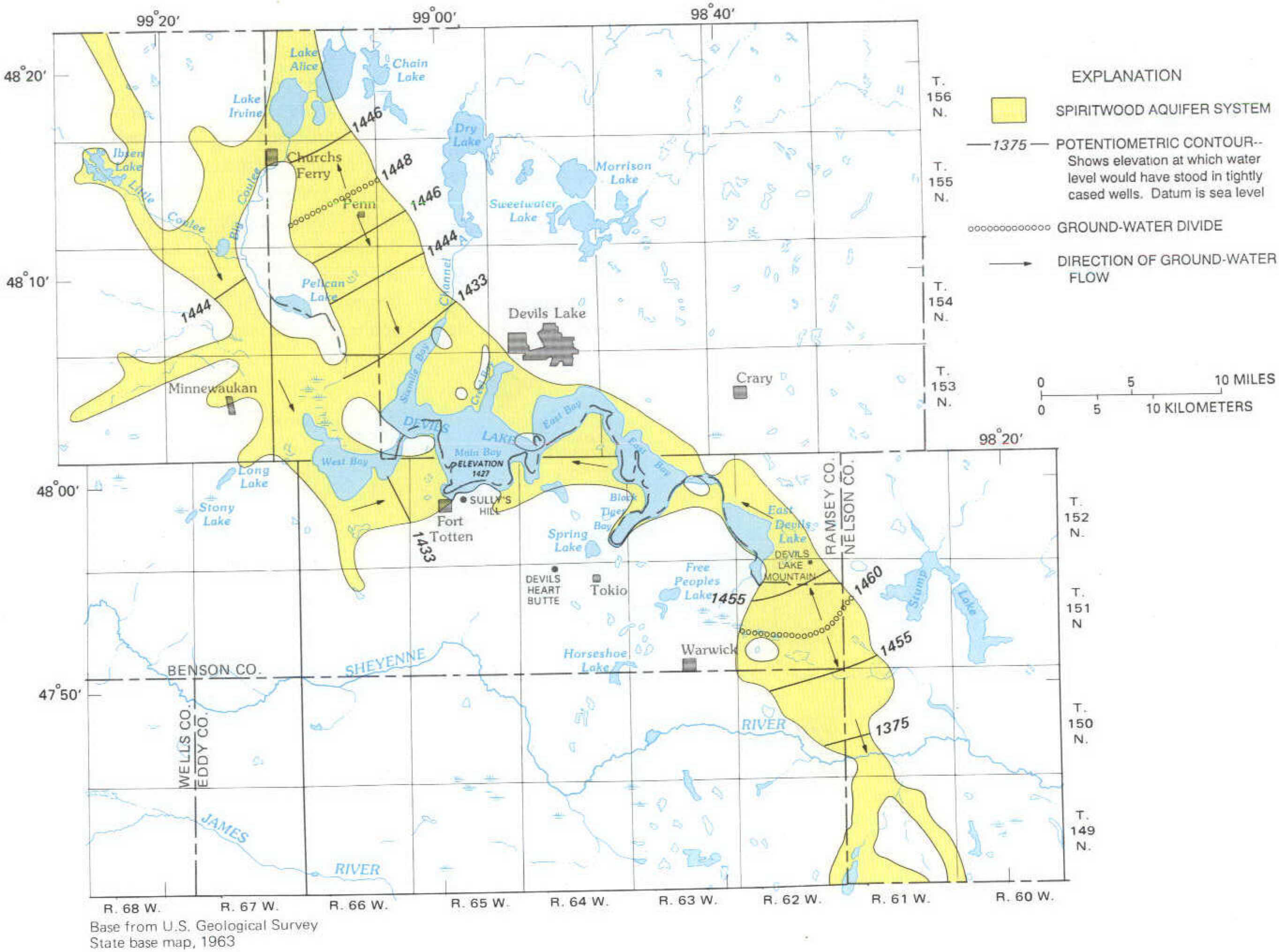


Figure 12. Potentiometric surface of and flow paths in the Spiritwood aquifer system in the Devils Lake area. (Modified from Pusc, 1993.)

system (Randich, 1977; Hutchinson and Klausing, 1980; Pusc, 1993).

On the basis of ground-water-level response to water-level fluctuations of Devils Lake, the Spiritwood aquifer system in the Devils Lake area has been divided into five flow segments (fig. 14): (1) Spiritwood aquifer near Minnewaukan; (2) Spiritwood aquifer near Lake Irvine; (3) Spiritwood aquifer near Devils Lake; (4) Spiritwood aquifer near Warwick; and (5) Spiritwood aquifer near the Sheyenne River (Randich, 1977; Hutchinson and Klausing, 1980; Pusc, 1993).

RELATION OF INFLOW TO OUTFLOW (WATER BALANCE OF DEVILS LAKE)

A water-balance model can be used to explain how the water level of Devils Lake responds to the interaction of the various components of the hydrologic cycle. The water-balance model is

inflow = outflow + storage change,

$$Q_i + P_{ls}(A_{ls}) + G = E_{ls}(A_{ls}) + S_c, \quad (1)$$

where

Q_i is surface-water inflow to Devils Lake, in acre-feet;

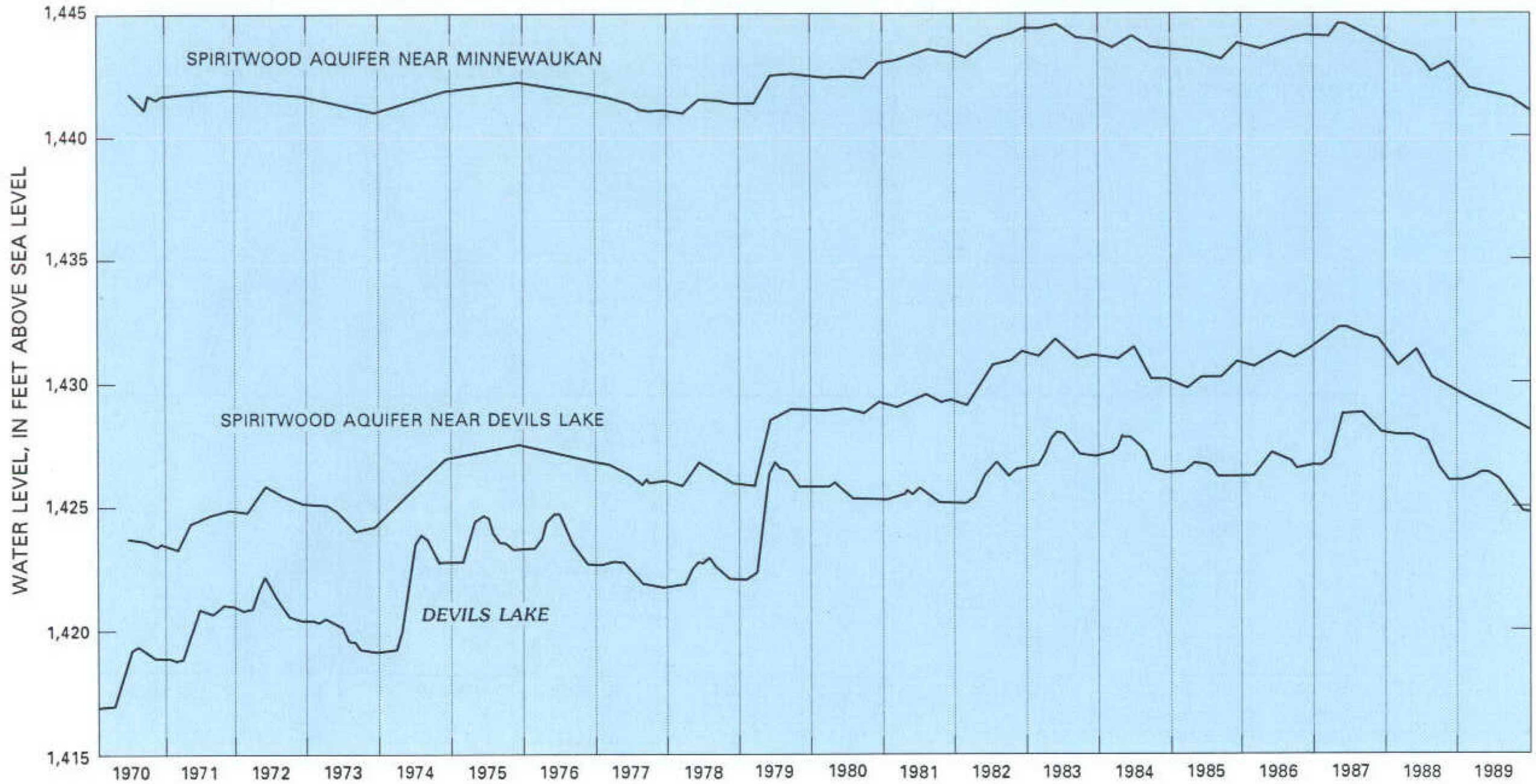


Figure 13. Water levels in wells completed in the Spiritwood aquifer system and water levels of Devils Lake, 1970-89.

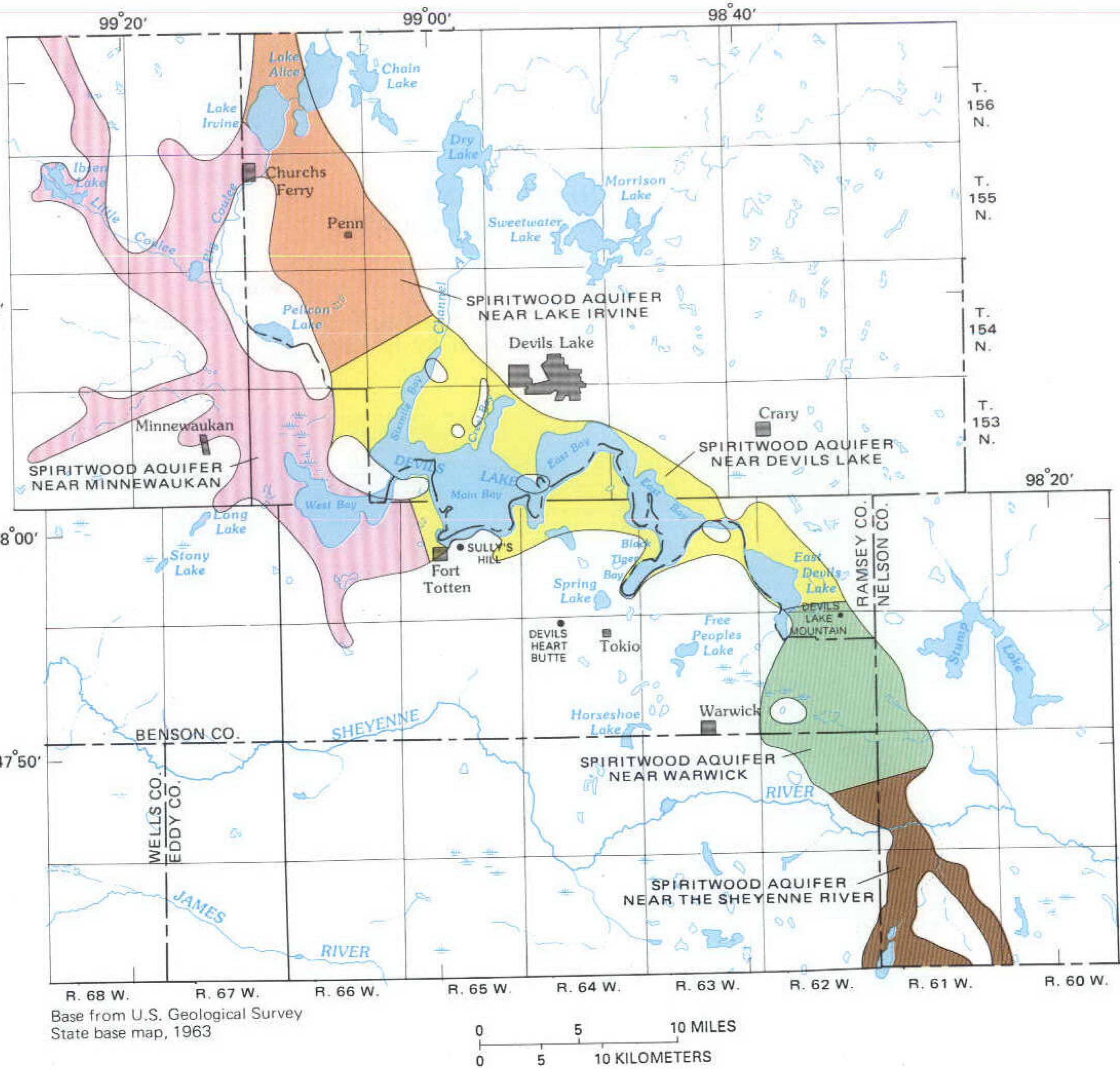


Figure 14. Subdivisions of the Spiritwood aquifer system in the Devils Lake area. (From Pusc, 1993.)

P_{ls} is precipitation falling on lake surface, in feet;

A_{ls} is lake-surface area, in acres;

G is ground-water inflow to Devils Lake, in acre-feet;

E_{ls} is evaporation from lake surface, in feet; and

S_c is storage change, in acre-feet.

Surface-water inflow to Devils Lake (Q_i) occurs in three ways: (1) inflow through Big Coulee (the major tributary to Devils Lake), (2) inflow through Channel A, and (3) inflow from small ungaged tributaries draining areas adjacent to Devils Lake. The amount of precipitation falling on the lake surface (P_{ls}) was estimated from precipitation gages at six locations around the shore of Devils Lake. Available data indicate that ground water (G) in the immediate area moves toward Devils Lake from all directions and enters the lake by movement through the lake sediments.

Evaporation from the lake surface (E_{ls}) occurs when energy is used to loosen bonds that hold water molecules together. Energy used in evaporation comes from heat stored in the water, warm air passing over the water, and, most importantly, absorbed solar radiation. Evaporation from Devils Lake was computed by the energy-budget method, which probably is the most accurate method for calculating evaporation. However, the energy-budget method is used infrequently in hydrologic studies because it requires measurement of energy sources, sinks, and heat stored in the water. To use the energy-budget method, a complete accounting is made of all radiation entering and leaving Devils Lake. A large amount of instrumentation and manpower is required to collect and process the data necessary to compute evaporation using this method. Much of the data are collected by instrumentation on a raft located on the lake (fig. 15).

Storage change (S_c) is computed from area-capacity tables that list the volume of water in storage and the lake-surface area (A_{ls}) for Devils Lake water levels that range from 1,401 to 1,440 feet above sea level.

Generalized Annual Hydrologic Model

The interaction of the various components of the hydrologic cycle (eq. 1) results in month-to-month and year-to-year fluctuations in water levels. On the basis of recorded water levels, a generalized annual hydrologic model can be outlined as follows:

1. In late fall or early winter, the water level in Devils Lake declines to a minimum. After freezeup and throughout the winter, the water level rises slightly because of ground-

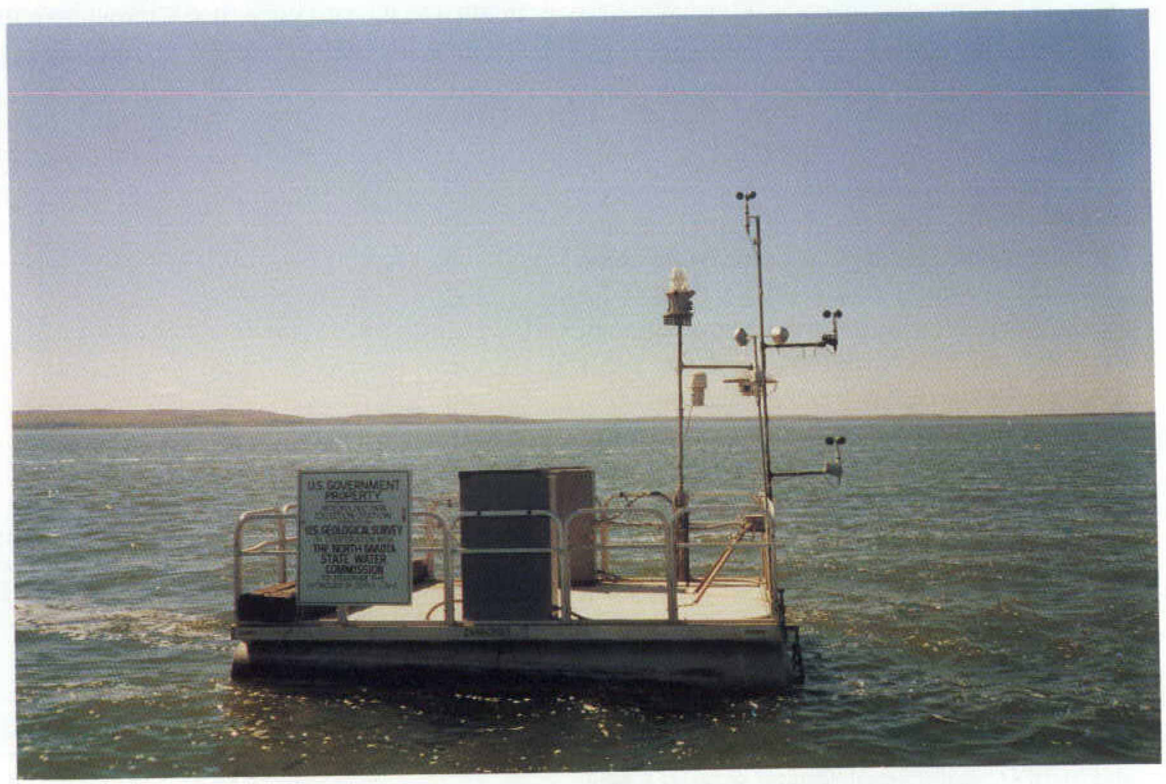


Figure 15. Meteorologic equipment on a raft at Devils Lake, 1988.

water inflow (positive S_c). Surface-water inflow usually is zero, and precipitation and evaporation usually are minor. Ground-water inflow is minor throughout the year.

2. In March through May, snowmelt and rain produce runoff from the basin into Devils Lake. The maximum water level occurs in April or May in drier years and in June or July in wetter years. In March through May, inflow [sum of Q_i, $P_{ls}(A_{ls})$, and G] exceeds outflow $[E_{ls}(A_{ls})]$ and the water level rises (positive S_c).

3. Sometime in April through July, outflow exceeds inflow and the water level begins to decline (negative S_c). The minimum water level occurs in late fall or early winter. Then the cycle is repeated.

Available hydrologic and climatologic data indicate that the generalized annual hydrologic model does not apply in some years. For example, in the dry years of 1934, 1935, and 1937, inflow during March through May did not exceed outflow, and the water level of Devils Lake actually declined at a time when it usually rises. Thus, in the dry years of the 1930's, surface-water inflow, precipitation falling on the lake surface, and ground-water inflow apparently always were less than evaporation from the lake surface.

Analysis of historic water-level fluctuations indicates that the water level in 1932, 1954, and 1971 differs significantly from the generalized annual hydrologic model. In 1932 and in 1971, water-level rises of about 0.5 foot occurred between September and November; these water-level rises were caused by generally intense rainfall over the entire Devils Lake Basin. The water-level rise that occurred during the summer and fall of 1954 (fig. 16) differs markedly from the generalized annual hydrologic model. In 1954, the water level of Devils Lake was virtually unchanged by snowmelt and spring rain. During June through November, however, the water level rose from 1,411.7 feet above sea level to a maximum of 1,414.4 feet above sea level (fig. 16). This water-level rise of 2.7 feet resulted in an increase in storage of 46,100 acre-feet. Two periods of intense rainfall contributed to the sustained runoff throughout the summer and fall of 1954. In June, rainfall totals in the Devils Lake Basin ranged from about 8.5 to 15 inches. The rainfall recharged the soil-moisture storage in the basin and filled the chain of lakes upstream of Devils Lake. Relatively normal precipitation in July and August was followed by generally intense rainfall over the entire Devils Lake Basin in September. The September rainfall caused the water level to continue to rise through November--a situation contrary to the normal pattern of water-level variations in Devils Lake.

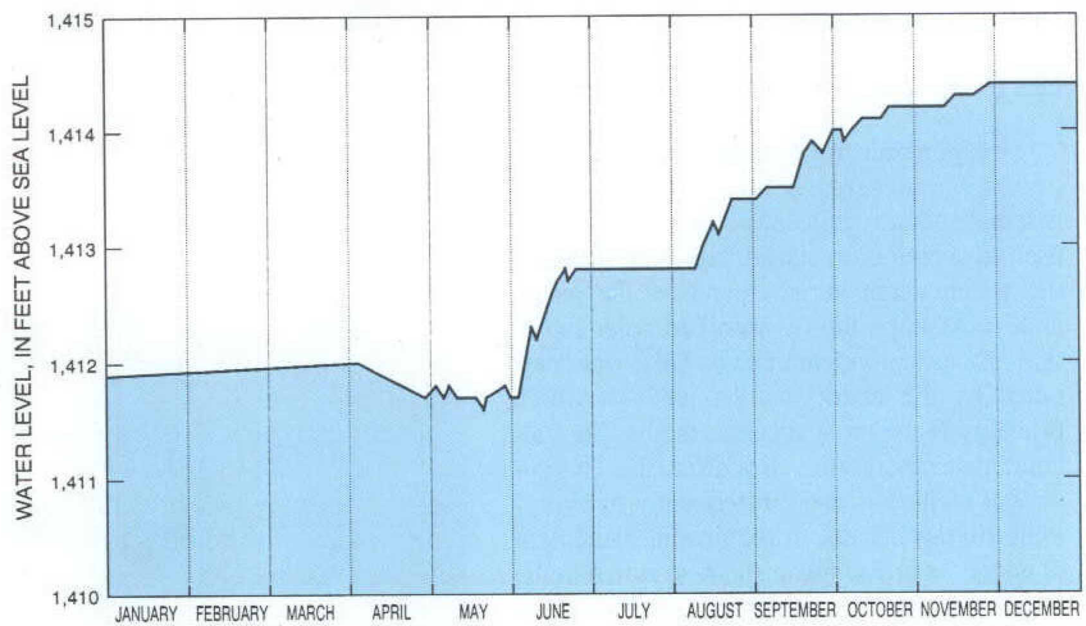


Figure 16. Water level of Devils Lake, January-December 1954.

Annual Water-Balance Variability

The water balance of Devils Lake for 1986-88 is listed in table 1 and shown in figure 17 (Wiche, 1991; Pusc, 1993). The storage change is positive when inflow is greater than outflow and negative when inflow is less than outflow.

In most years, the largest percentage of inflow to Devils Lake is precipitation falling on the lake surface. During 1986-88, precipitation ranged from 31 to 72 percent of the annual inflow to Devils Lake. Only during years when floods occur on tributaries to Devils Lake is surface-water inflow greater than precipitation falling on the lake surface. Large annual variability of inflow from precipitation occurs for two reasons: (1) Precipitation can vary greatly from year to year and (2) the surface area of Devils Lake increases as water levels rise and decreases as water levels decline. The effect that changes in lake-surface area have on inflow from precipitation can best be illustrated by the following example. In 1988, 12.84 inches of precipitation fell on Devils Lake when the surface area of the lake was 55,500 acres (1,427.5 feet above sea level). This precipitation produced an inflow of 59,400 acre-feet. If 12.84 inches of precipitation fell on Devils Lake when the surface area of the lake was 41,000 acres (1,421 feet above sea level), the precipitation would produce an inflow of only 43,900 acre-feet.

In general, the water level of Devils Lake fluctuates in response to climatic variability, but the hydrologic characteristics of the Devils Lake Basin distort the hydrologic response. Potholes and lakes that eventually drain into Devils Lake have the ability to retain a significant part of the runoff, especially in the drier years. Thus, the annual surface-water inflow varies greatly from year to year (table 1). For example, surface-water inflow in 1987 was 174,000 acre-feet, but surface-water inflow in 1988 was only 19,700 acre-feet. During the last 50 years, surface-water inflow has ranged from near zero for several years in the 1930's to about 248,000 acre-feet in 1979 (Wiche and others, 1986).

Ground-water inflow is only a small percentage of total inflow but is relatively constant from year to year. During periods of no surface-water inflow and no precipitation, ground-water inflow is the major inflow component. However, ground-water inflow is not sufficient to maintain the water level of Devils Lake. Sufficient ground-water monitoring was not done before 1986 to estimate the annual variability of ground-water inflow.

Table 1. Computed water balance of Devils Lake for 1986-88

Year	Surface-water inflow to Devils Lake (acre-feet)		Precipitation falling on lake surface times lake-surface area (acre-feet)		Ground-water inflow to Devils Lake (acre-feet)		Evaporation from lake surface times lake-surface area (acre-feet)		Storage change (acre-feet)[1]
1986	58,100	+	102,100	+	3,000	=	139,700	+	23,500
1987	174,000	+	77,900	+	3,000	=	185,800	+	69,100
1988	19,700	+	59,400	+	3,000	=	183,700	-	101,600

[1]Positive storage change indicates an increase in water level; negative storage change indicates a decrease in water level.

Evaporation is the only mechanism that removes water from Devils Lake. Annual evaporation varies from year to year, although not as much as surface-water inflow. Evaporation during 1987 and 1988 was about one-third greater than evaporation during 1986. Evaporation during 1986 was about normal.

A consortium of State and Federal agencies led by the North Dakota State Water Commission developed a report that details 28 options for stabilizing the water level of Devils Lake (North Dakota State Water Commission, 1990). All of the options outlined in the report require an inlet to Devils Lake and an outlet from Devils Lake. Water would flow into Devils Lake via a conveyance system when the water level of the lake is less than a specified elevation, and water would be released from the lake when the water level is greater than a specified elevation. The water-balance equation was used to compute the

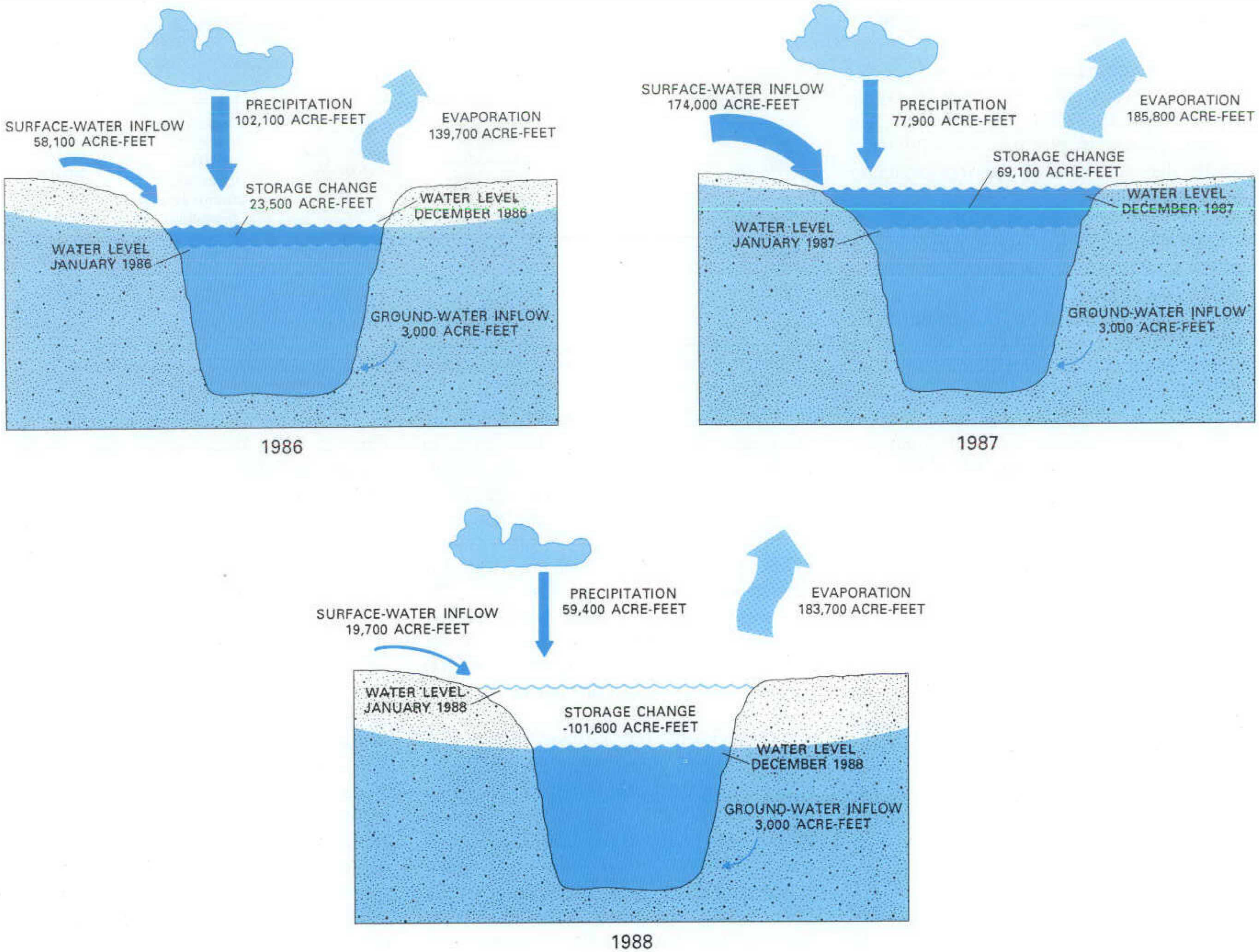


Figure 17. Water balance of Devils Lake for 1986-88.

amount of inflow required to stabilize the water level of Devils Lake (table 2).

During years when both precipitation and evaporation are normal, about 68,900 acre-feet of surface-water inflow is needed to maintain the water level of Devils Lake at 1,425 feet above sea level. Surface-water inflow to Devils Lake was greater than 68,900 acre-feet for only 7 years from 1931 to 1990, and six of the seven largest inflows occurred from 1969 through 1987 (fig. 18). Thus, during most years, the water level of Devils Lake declines. However, during flood years, the water level can rise by 3 to 6 feet because of surface-water inflow. The cumulative effect of the six largest surface-water inflows from 1969 through 1987 was a general rise in water level from 1,410.5 feet above sea level in 1969 to 1,428.8 feet above sea level in 1987, the highest level in about 100 years. During years when below-normal precipitation and above-normal evaporation occur, about 103,600 acre-feet of surface-water inflow is needed to maintain the water level of Devils Lake. Because tributary inflow usually is less than 20,000 acre-feet, especially when precipitation is below normal, about 84,000 acre-feet of water would need to be added to Devils Lake to maintain the water level during drier years.

Table 2. Computed water balance of Devils Lake for a stable water level and various climatic conditions

[A water-level elevation of 1,425 feet above sea level and a lake-surface area of 50,990 acres were used in all computations]

	Surface-water inflow to Devils Lake (acre-feet)		Precipitation falling on lake surface times lake-surface area (acre-feet)		Ground-water inflow to Devils Lake (acre-feet)		Evaporation from lake surface times lake-surface area (acre-feet)		Storage change (acre-feet)
Below-normal precipitation and above-normal evaporation	103,600	+	57,100	+	3,000	=	163,700	+	0
Normal precipitation and normal evaporation	68,900	+	70,400	+	3,000	=	142,300	+	0
Above-normal precipitation and below-normal evaporation	23,000	+	95,400	+	3,000	=	121,400	+	0

SUMMARY

Devils Lake Basin, in northeastern North Dakota, is a 3,810-square-mile closed drainage basin. About 3,320 square miles of the total 3,810 square miles is tributary to Devils Lake. The Devils Lake area has been a popular recreational area, and Devils Lake has been a productive sport fishing lake intermittently during the last 110 years.

Geologic features of the Devils Lake Basin primarily are a result of the depositional and erosional effects of continental glaciation. Lake deposits and glacial till mantle the land surface over much of the area around Devils Lake as well as most of the Devils Lake Basin. Pierre Shale underlies the glacial sediments in most of the Devils Lake area.

Preglacial rivers, such as the ancient Cannonball River, carved deep valleys into the Pierre Shale. Sand and gravel deposited in the valley of the ancient Cannonball River is termed the Spiritwood aquifer system. Test drilling indicates that the Spiritwood aquifer system underlies Devils Lake and East Devils Lake.

Since glaciation, the water level of Devils Lake has fluctuated from about 1,454 feet above sea level, the natural spill elevation of the lake, to about 1,400 feet above sea level. Historic water levels have fluctuated from

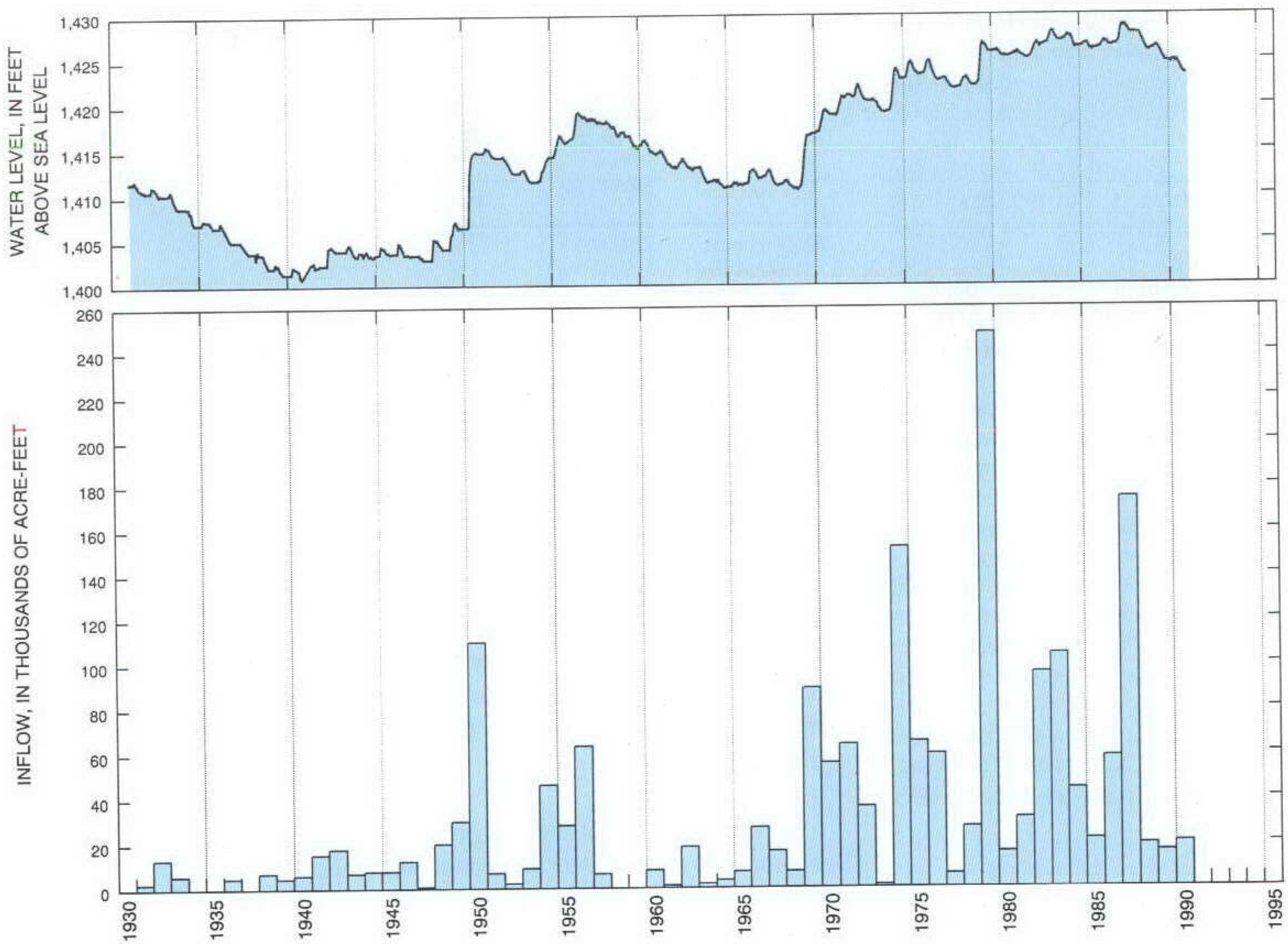


Figure 18. Water levels and annual surface-water inflow of Devils Lake, 1931-90.

1,438 feet above sea level in 1867 to 1,400.9 feet above sea level in 1940. In 1987, the water level of Devils Lake reached a peak of 1,428.8 feet above sea level, which is the highest water level in almost 100 years. By 1991, however, the water level had declined to 1,423.5 feet above sea level.

Shallow ground water in the Devils Lake area occurs mainly in lake deposits and glacial till. In general, ground water in the immediate area of Devils Lake moves toward the lake from all directions. Shallow ground water moves slowly toward the many potholes and lakes throughout the basin and interacts with Devils Lake only in the area immediately surrounding Devils Lake.

On the highlands away from Devils lake, ground water that is not returned to the atmosphere by transpiration or evaporation moves slowly downward through the lake deposits and glacial till and into the Spiritwood aquifer system. Ground water in the Spiritwood aquifer system moves toward Devils Lake, Lake Irvine, or the Sheyenne River. Near Devils Lake, ground water moves slowly upward from the Spiritwood aquifer system through the overlying lake deposits, glacial till, and lake sediments into Devils Lake.

In most years, the largest percentage of inflow to Devils Lake is precipitation falling on the lake surface. During 1986-88, annual precipitation falling on the lake surface ranged from 59,400 acre-feet to 102,100 acre-feet. Only during years when floods occur on tributaries to Devils Lake is surface-water inflow greater than precipitation falling on the lake surface. During 1986-88, annual surface-water inflow ranged from 19,700 acre-feet to 174,000 acre-feet. Ground-water inflow is only a small percentage of total inflow but is relatively constant from year to year. During 1986-88, the annual ground-water inflow was estimated to be 3,000 acre-feet. Evaporation is the only mechanism that removes water from Devils Lake. During 1986-88, estimated annual evaporation ranged from 139,700 acre-feet to 185,800 acre-feet.

The water-balance equation was used to compute the amount of inflow required to stabilize the water level of Devils Lake. During years when both precipitation and evaporation are normal, about 68,900 acre-feet of surface-water inflow is needed to maintain the water level of Devils Lake at 1,425 feet above sea level.

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