

Featured Lake Devils Lake, ND

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A Rising Prairie Sea

In October 2004, I chartered a small plane in Jamestown, North Dakota, to obtain aerial photos of Devils Lake, the largest natural lake in North Dakota and the place where I began my career in limnology 40 years earlier. Back then, in 1964, Devils Lake covered about 30 square miles, had a maximum depth of 10 feet, and held around 145,000 acre-feet of water (Figure 1).

Devils Lake is located 75 air miles directly north of Jamestown. To my amazement, the lake began to appear on the far horizon shortly after we had departed Jamestown Airport and had reached an altitude of about 10,000 feet. My amazement grew as the lake came into full view, its vastness evident by the fact that it now covered more than 200 square miles (Figure 2). As we circled the lake, I searched for the site of our limnological field lab, presumably submerged under 30 or more feet of water. Indeed, the rather unimposing lake that I had worked on during the 1960s had become a rising “prairie sea.”

Lake Origin and Lake Rise and Fall . . . and Rise Again

The Devils Lake Basin is a closed basin (endorheic) covering about 3,900 square miles in northeastern North Dakota (Figure 3). The basin was carved from earth and rock by a continental glacier that covered much of North America during the Pleistocene Epoch. As the glacier advanced, excavated materials were deposited along its leading edge, creating a series of prominent ridges or terminal moraines marking the glacier’s farthest movement. Roughly 10,000 years ago, as the glacier retreated, its meltwaters gradually filled a portion of the basin,

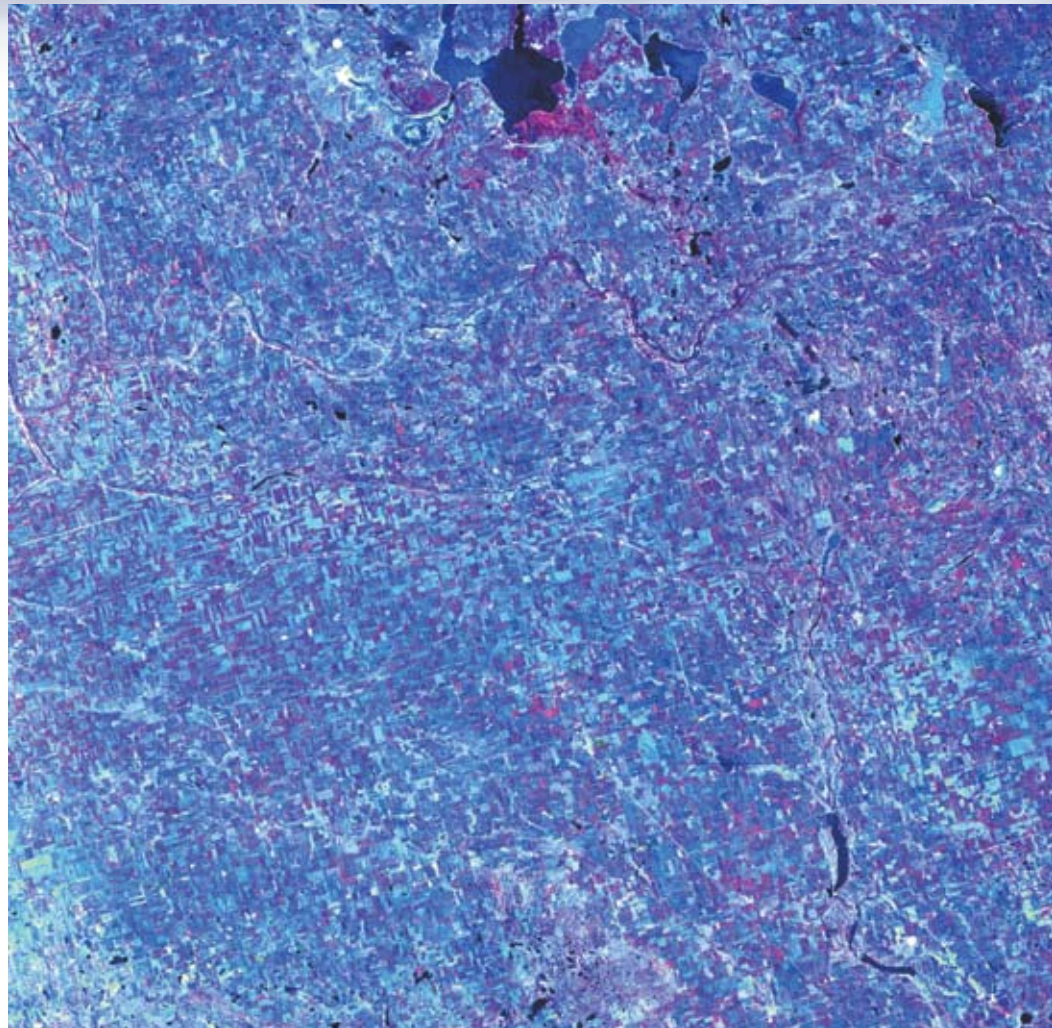


Figure 1. Landsat color infrared satellite image of Devils Lake, North Dakota, June 1973. The largest and darkest blue body of water is Devils Lake Main Bay. Creel Bay, about three miles long, is the finger-like projection extending directly north from Main Bay. Sixmile Bay branches off along the west side of Main Bay before bending north for several miles. East and West Stump Lakes appear in the far right-hand side of the photo. Source: EROS, U.S. Geological Survey, Sioux Falls, SD.

producing a vast proglacial lake dammed by morainal deposits.

Over time, in response to drier and warmer climates, the lake receded periodically, leaving behind abandoned

beaches, or strand lines. Based on the location of the highest remaining strand line, geologists estimated that the lake originally covered about 435 square miles and reached a surface elevation of about

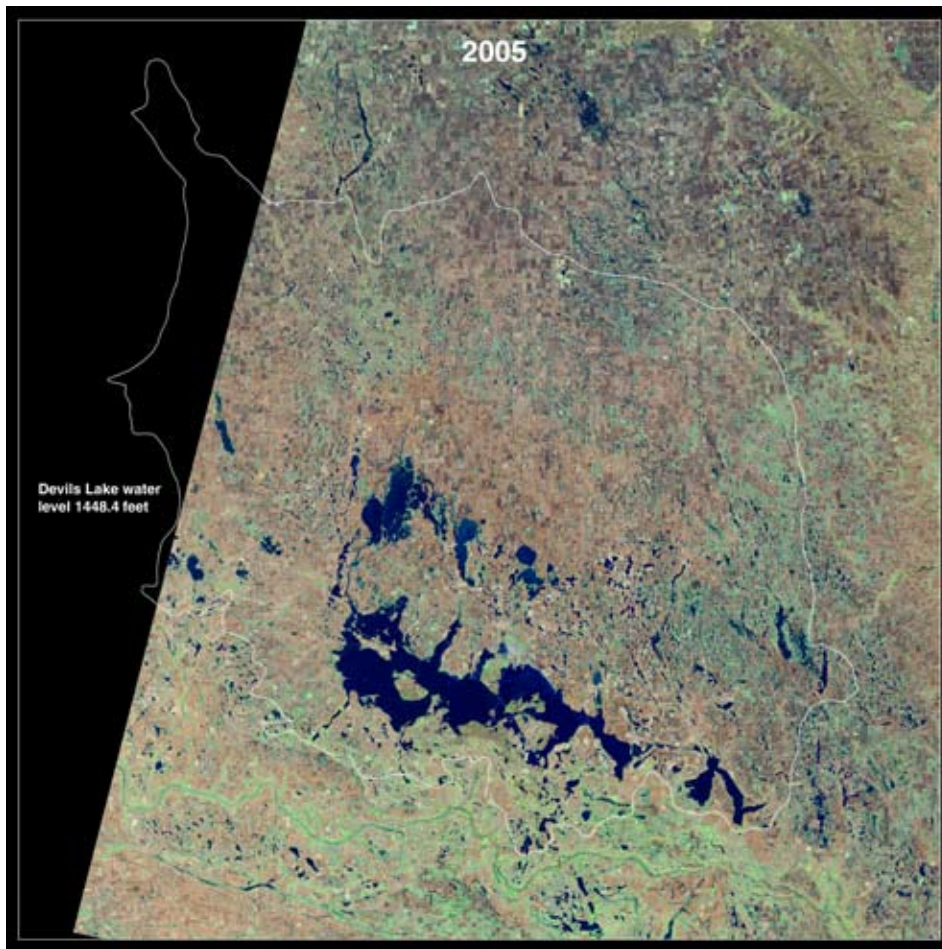


Figure 2. Landsat natural color satellite image of Devils Lake, North Dakota, April 2005. Source: North Dakota Water Science Center, U.S. Geological Survey, Bismarck.

1,459 feet above mean sea level (amsl). At this elevation, lake volume would have been roughly 5.3 million acre-feet.

Native Americans called this ancient lake “Minnewaukan,” meaning Spirit Water. European settlers renamed the lake Devils Lake in deference to an Indian legend about the drowning of a large party of Sioux warriors whose canoes had capsized in the lake’s treacherous storm-tossed waters. Today, what was once Lake Minnewaukan has since been reduced to several remnant lakes – including Devils Lake – scattered across the south-central portion of the basin (Figure 3).

Following the lake’s origin, water levels fluctuated roughly 20 to 40 feet every few hundred years in response to climate variations. Sediment analyses indicated that the lake may have been completely dry 6,500 years ago (Callender 1968). In 1867, when lake surface elevation was first measured, the lake stood at elevation 1,438 feet amsl,

covered about 130 square miles, and contained about 1.5 million acre-feet of water. By 1940, after several years of extreme drought, the lake had diminished even further, dropping to a record-low elevation of 1,401 feet amsl and covering only 10 square miles (Wiche and Pusc 1994).

Since 1940, the lake has exhibited a dramatic resurgence – particularly over the past 15 years – largely in response to a substantially wetter climate (Figure 4). By 2006, the lake had risen nearly 50 feet, reaching its modern-day maximum elevation of 1,449.2 feet amsl on May 9. By then, the lake covered about 240 square miles and contained about 3.3 million acre-feet of water.

The rising lake has flooded a major portion of the Devils Lake region. The town of Minnewaukan (population 318), located eight miles west of the lake in 1992, is now partly under water (Figure 5). Rising lake waters also threaten the

city of Devils Lake, a community of about 7,200 inhabitants located on the lake’s north shore (Figure 6). The flooding has perhaps given credence to another Indian legend, claiming that the lake once overflowed and flooded the entire world.

Lake Hydrology and Climate

Devils Lake consists of three principal basins: West Bay, Main Bay, and East Bay. Several smaller bays (Sixmile, Creel, Fort Totten, Mission, and Black Tiger) indent the shoreline of the combined basins (refer back to Figure 3). In 1964, West Bay was largely dry. Main Bay stood at elevation 1,411 feet amsl and covered about 20 square miles. East Bay, at roughly the same elevation, covered about 11 square miles and was separated from Main Bay by the Rock Island State Military Reservation (reference: 1950 USGS 15’ quadrangle maps titled “Camp Grafton, N.Dak.” and “Grahams Island, N.Dak.”). Pope (1909) estimated that flow from Main Bay into East Bay would have ended when lake surface elevation had fallen to 1,418 feet amsl.

The three basins have since merged along with Pelican Lake to the west and several smaller lakes to the east, including East Devils Lake, Swan Lake, West Stump Lake, and East Stump Lake (refer to Figures 2 and 3). Overflow water from Devils Lake began reaching the Stump Lakes in 1999; the surface elevation of Devils Lake then stood somewhere between 1,446 and 1,447 feet amsl. If Devils Lake were to rise another 12 feet, to elevation 1,459 feet amsl, lake water would begin to flow out of the basin into the Sheyenne River. The Sheyenne River Valley meanders along an east-west line located about 10 miles south of Devils Lake. The river originates about 30 miles west of the lake and flows in a southeasterly direction before joining the Red River of the North near Fargo, North Dakota (refer to Figure 3).

Devils Lake receives nearly all of its surface water runoff from a chain of remnant lakes located a few miles north. These lakes drain into Devils Lake via (1) an intermittent stream flowing out of Lake Irvine through Big Coulee and (2) a manmade drainage canal called Channel A, which connects Dry Lake with Devils Lake’s Sixmile Bay (refer back to Figure 3). Surface runoff also enters

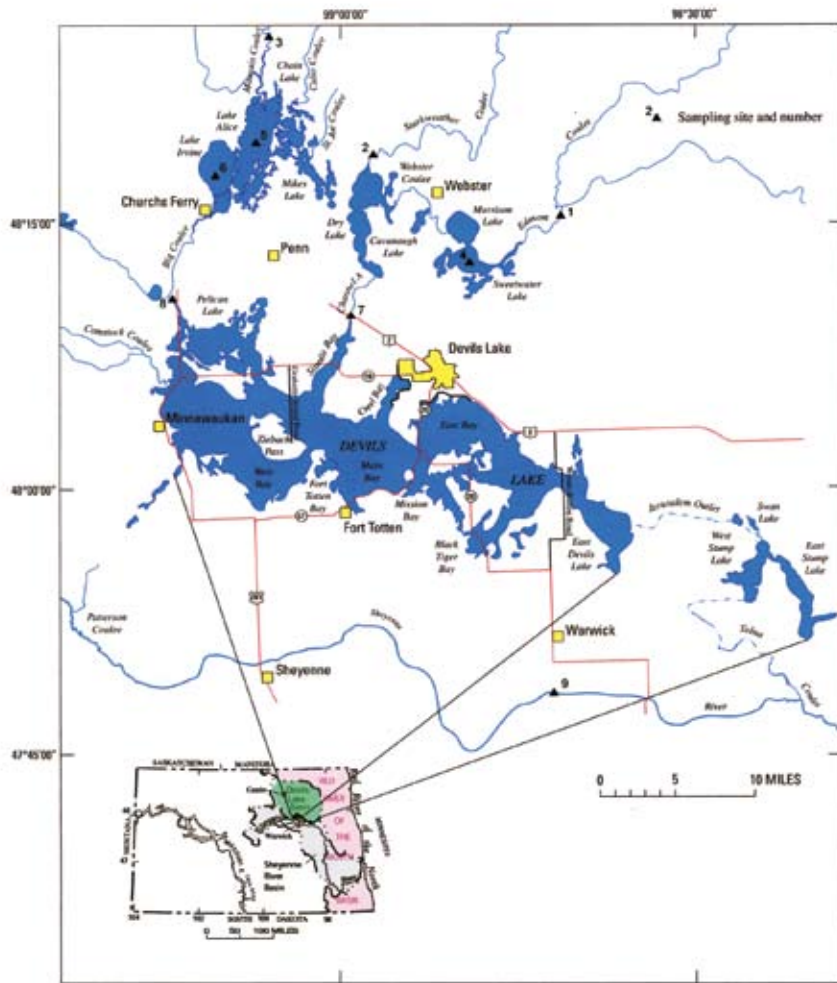


Figure 3. Map of North Dakota and the remnant lakes of ancient Lake Minnewaukan. From Wiche et al. 2000.

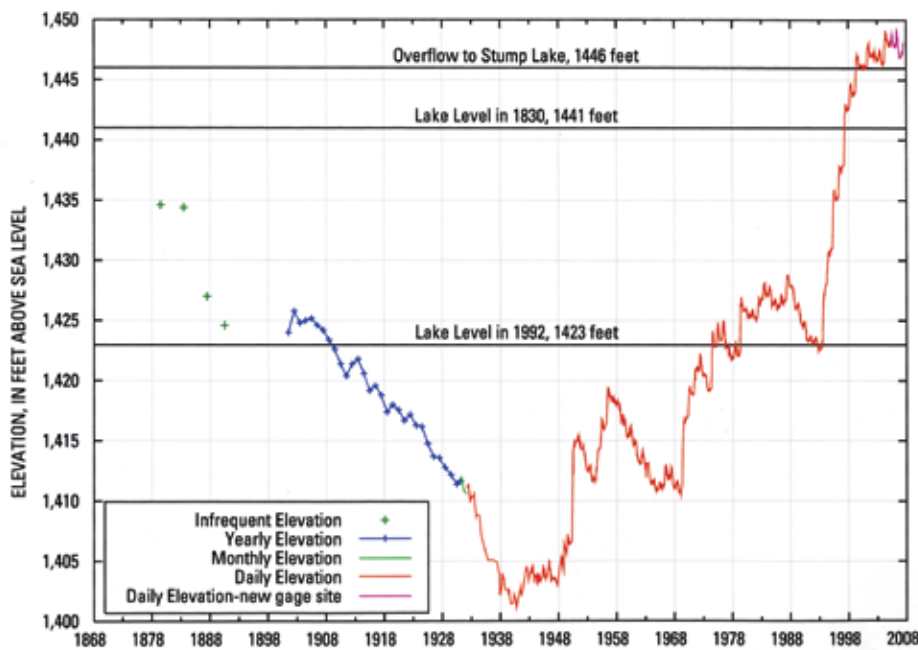


Figure 4. Surface elevations, Devils Lake, North Dakota, 1879-2008. Source: North Dakota Water Science Center, U.S. Geological Survey, Bismarck.

from adjacent upland terrain, but this is a comparatively small source. Overall, surface-water inflow is highly variable from year to year, as indicated by inflow records for years 1986 through 1988 (Table 1).

Devils Lake also receives appreciable amounts of water from direct precipitation, which likewise varies considerably from year to year (Table 1). Precipitation contributed roughly 63 percent of the lake's total inflow in 1986, 31 percent in 1987, and 72 percent in 1988 (Table 1). Moreover, with an increase in lake-surface area, the volume of water received via direct precipitation increases proportionally. Although groundwater volume varies little from year to year, this source contributes only a small percentage of total inflow, averaging 2.4 percent between 1986 and 1988 (Table 1).

Over a longer period of record, total annual inflows ranged from near-zero during the drought-stricken 1930s to nearly 400,000 acre-feet in 1993. Inflows, which had averaged 65,500 acre-feet annually between 1950 and 1993, increased to 317,000 acre-feet annually between 1993 and 2000. Years 1993 through 1995 contributed 24 percent of all inflow to Devils Lake during the period 1950 to 1995 (U.S. Geological Survey 1997).

Lacking a natural surface outlet below elevation 1,459 feet amsl, Devils Lake loses water largely to evaporation. Evaporation removed 86 percent of total inflow in 1986 and 73 percent in 1987. In 1988, the evaporation amount exceeded the total inflow by more than 200 percent, resulting in a net lake-water loss of more than 100,000 acre-feet (Table 1). Some water is lost through groundwater seepage, but the amount is comparatively small. Additionally, to stabilize and hopefully lower lake levels, an emergency outlet channel was constructed and first opened in August 2005. Since then, the outlet has removed about 340 acre-feet of water, representing about one-hundredth of one percent of the lake's total volume. (More information about the outlet follows.)

The climate of the Devils Lake region is typical of the Northern Great Plains. Annual temperatures average between 36° and 42° F, with July temperatures



Figure 5. Aerial view of the town of Minnewaukan. Photo by the author, October 9, 2004.



Figure 6. Aerial view of the city of Devils Lake. Photo by the author, October 9, 2004.

averaging 69° F and January temperatures averaging 6° F (U.S. Department of Commerce 2002). Bingham and de Percin (1955) reported that the highest and lowest temperatures on record were (and may still be) 112° and minus 46° F, respectively. Precipitation, including 30 inches of snowfall on average, averages 18.9 inches per year, roughly half of which falls during May, June, and July (U.S. Department of Commerce 2002). In an environmental assessment of the Devils Lake region as a possible winter-warfare

testing site for the U.S. Army, Bingham and de Percin (1955) described the area as one featuring “severe winters,” with climatic conditions resembling those “in Kazan and Chkalovo in the upper Volga River, in Barnaul in south central Siberia, and in Harbin in central Manchuria.”

Endorheic Lake Chemistry

By 1940, Devils Lake had nearly evaporated from the face of the earth. Lake volume then was approximately 37,000 acre-feet, or less than one percent

of the volume of Lake Minnewaukan. Anderson (1969) reported that Devils Lake was less than one meter deep, and that most of Creel Bay was dry.

As the lake evaporated, it became increasingly saline. In November 1948, Swenson and Colby (1955) obtained a salinity reading of 25,000 parts per million (ppm as total dissolved solids), the highest recorded value for Devils Lake. By then, in response to improved moisture conditions, lake volume had increased to about 51,000 acre-feet, raising the surface elevation to about 1,406 feet amsl. Since TDS measurements were discontinued between 1923 and 1948, the salinity of Devils Lake during its record-low elevation of 1,401 feet in 1940 is unknown, although it is likely that the lake had become extremely brackish, with TDS values easily exceeding 25,000 ppm. TDS measurements prior to 1923 (n=9) ranged from 8,471 ppm in 1899, when TDS was first measured, to 15,889 ppm in 1920 (Swenson and Colby 1955).

The extraordinary increase in lake volume over the past 15 years has greatly diluted Devils Lake water, although salinity varies considerably throughout the recombined lake system. An upward-trending salinity gradient extends from Pelican Lake at the west end of the Devils Lake complex to Stump Lake at the east end. In 1949, when the lakes were separate bodies of water, Swenson and Colby (1955) reported TDS concentrations of roughly 2,300 ppm in Devils Lake’s Sixmile Bay, 13,000 ppm in the lake’s Main Bay, 41,000 ppm in East Devils Lake, and up to 106,000 ppm in East Stump Lake. Fifty years later, in 1999, TDS concentrations ranged from less than 400 ppm in Pelican Lake to slightly more than 6,000 ppm in East Devils Lake (Elstad 2002). Overflow waters from Devils Lake had a dilution effect on the Stump lakes, greatly reducing their salinities. By September 2007, when Devils Lake and the two Stump lakes had completely merged, the TDS concentration in East Stump Lake stood at 4,000 ppm (Website data, U.S. Geological Survey), roughly 27 times lower than the TDS concentration in 1949.

Sulfate is the predominant ion in Devils Lake, comprising nearly 60 percent of the TDS load in 1967 (Table 2). Sodium is second, representing 20-

Table 1. Water Budget, Devils Lake, North Dakota, 1986-1988.¹

	1986	1987	1988
Water Gain (Acre-Feet)			
Surface Water	58,100	174,000	19,700
Direct Precipitation	102,100	77,900	59,400
Groundwater	3,000	3,000	3,000
Total	163,200	254,900	82,100
Water Loss (Acre-Feet)			
Evaporation	139,700	185,800	183,700
Water Stored (Acre-Feet)*	+23,500	+69,100	-101,600

*Plus value indicates lake-volume increase; minus value indicates lake-volume decrease.

Source: Wiche and Pusc (1994).

Table 2. Water Chemistry, Devils Lake, North Dakota, 1919-2001.

	1919 ¹	1949 ⁴	1967 ⁵	2001 ⁶
Lake Elevation (feet above msl)	1,416	1,406	1,413	1,448
Total Dissolved Solids, mg/liter	13,462	14,600	11,500	1,650
Specific Conductance, μ mhos/cm	NA ²	15,800	NA	2,400
Bicarbonate, mg/liter	458	764	700	NA
Carbonate, mg/liter	305	66	125	NA
Calcium, Dissolved, mg/liter	70	70	62	67
Magnesium, Dissolved, mg/liter	844	662	485	82
Sodium, Dissolved, mg/liter	2,548	3,440	2,800	265
Potassium, Dissolved, mg/liter	204	295	268	38
Silica (SiO ₂), Dissolved, mg/liter	NA	10	5	9-50 ⁷
Chloride, Dissolved, mg/liter	1,310 ³	1,610	1,200	125
Sulfate, Dissolved, mg/liter	7,187	7,490	6,800	710
Iron, Dissolved, μ g/liter	NA	160	3,300	<1

¹ Source: Young (1924).

² Not Available.

³ Reported as “chlorine.”

⁴ Source: Swenson and Colby (1955); mean of 20 samples collected June 18.

⁵ Source: Anderson (1969); data from samples collected in June; values derived from time-series plots.

⁶ Source: U.S. Geological Survey; values derived from time-series plots.

⁷ Range of values between 1990 and 1992.

25 percent of the total ionic load. The percentile composition of major ionic components remained fairly constant between 1911 and 1948 (Swenson and Colby 1955), and again between 1948 and 1967; this indicated that evaporation

and not other factors (e.g., geothermal saltwater intrusions) accounted for the lake’s increased mineralization (Anderson 1969). The calcium percentage has increased, inexplicably, since 1967, while percentages for sulfate, chloride, and sodium have decreased (Table 2).

Disappearance of a Commercial Fishery

European settlement of the Devils Lake region began in earnest following the establishment of a U.S. military outpost called Fort Totten on the south shores of Devils Lake in 1867. Settlers soon discovered that the lake offered a variety of water-resource benefits. Beginning in 1883, a side-wheel steamer christened the *Minnie H.* (Figure 7) plied the waters of Devils Lake carrying cargo and passengers between lakeside towns and other settlements. As the lake continued to recede, however, steamboat travel became increasingly risky as shoals and other underwater hazards developed in an ever-shrinking lake. By 1907, the lake had shoaled from its 1883 maximum depth of 35 feet to a depth of 25 feet in 1907. The *Minnie H.* was finally retired in 1909, replaced by railroads and other faster, more efficient, and, perhaps, safer forms of transportation.

According to early settlers, “swarms” of northern pike inhabited Devils Lake. The abundance of these fish, identified as *Esox lucius* (Young 1924), led to the development of a commercial fishery. During the 1880s, tens of thousands of pike were harvested annually and shipped by railroad to Minneapolis, Chicago, and other large Midwestern cities. The once-prodigious fishery finally disappeared by 1905, its demise attributed to one or more possible factors including overfishing, loss of spawning grounds by agricultural land-use, disease, parasites, suffocation during prolonged lake ice cover (winter kill), and intolerance to high salinity (Young 1924). Among these, high salinity was thought to be the chief contributing factor to the lake’s declining fishery (Young 1923, 1924). Salinities in Devils Lake’s Main Bay increased from 9,448 ppm in 1907 (Pope 1909) to 14,452 ppm in 1918 (Nerhus 1920). Salinities of 18,000 ppm will kill northern pike, although salinities down to 7,000 ppm can “reduce or prevent spawning.” (Scott and Crossman 1973). By 1924, only the salt-tolerant brook stickleback (*Culaea inconstans*) could be found in Devils Lake (Young 1924). Although this species can tolerate salinities up to 17,500 ppm, it becomes increasingly inactive as salinities approach 25,000 ppm (Scott and Crossman 1973).



Figure 7. Steamboat Minnie H. at boat landing for Chautauqua, Devils Lake, North Dakota, date unknown. Source: State Historical Society of North Dakota, Bismarck.

The North Dakota Biological Station

Despite the disappearance of fish and other aquatic life in Devils Lake, Pope (1909) and other scientists believed that the lake's once-thriving and well-balanced ecosystem could be reclaimed. Although they admitted that pike and other game fish would probably continue to perish in the lake's increasingly saline waters, they argued that the lake's "alkaline salts" were "not necessarily prohibitive to the acclimatization of certain species of fish." (Swenson and Colby 1955). To prove their point, they began conducting experimental fish introductions in 1908, stocking the lake with chiefly yellow perch (*Perca flavescens*), but even these fish failed to survive (Young 1924).

In 1909, while efforts continued to restore the fishery and study the unusual brackish-water ecology of North Dakota's largest natural lake, the North Dakota Legislature authorized the construction of the North Dakota Biological Station at Devils Lake. The facility – a spacious, two-story structure (Figure 8) – was located along the east shore of Creel Bay. Several prominent scientists from across the United States spent time at the station conducting research or observing field and lab procedures. These scientists included Chauncey Juday – a "founding father" of limnology in North America – and C.H. Edmondson of the University of Oregon,

who studied the lake's protozoans. E.A. Birge, another "founding father" from the University of Wisconsin, identified crustaceans and provided advice on limnological methods and apparatus. In 1923, the station was closed after the North Dakota Legislature failed to appropriate operating funds. The North Dakota Game and Fish Department used

the station as a research laboratory until 1931 when it was turned over to the Devils Lake Park Board. The Park Board then passed the station on to the Devils Lake Jaycees, a civic organization, who used the building as a clubhouse until it was finally abandoned during the 1950s.

The Life of Devils Lake: 1924

Following the station's closure, R.T. Young, a biology professor at the University of North Dakota and the station's director, published a book (Young 1924) titled *The Life of Devils Lake, North Dakota* [author's note: *I have an original copy*]. Young's book, a milestone treatise on the limnology of Devils Lake, covered station research between 1909 and 1923. Young generally described the lake's biota as a relatively sparse flora and fauna consisting of many species well-adapted to brackish waters. In addition to sticklebacks being the only fish in Devils Lake, Young reported that the lake contained no reptiles and only two amphibians: *Rana pipiens*, the pickerel frog, and *Ambystoma tigrinum*, the tiger salamander. Bishop (1962) referred to Devils Lake as the type locality for *Ambystoma tigrinum diaboli* Dunn, also called the Devil's Lake tiger salamander.



Figure 8. Researchers with equipment at the North Dakota Biological Station, circa 1914. In March 1995, as rising lake waters threatened to engulf the building, the upper half of the structure was lifted off the lower rock walls and moved to higher ground on the lake's south shore. Purchased by a private party, the building was restored and converted to a family residence. Photo taken by J.V. Harrison of Devils Lake, North Dakota.

Among invertebrates, protozoans were most diverse (106 species), followed by rotifers (31 species), nematodes, or roundworms (9 genera, one species), cladocerans (11 species), copepods (9 species), and hydracarina, or water mites (4 or 5 species). Other invertebrates included a planarian, or flatworm (*Gyratrix hermaphroditus*), a gastrotrich (*Chaetonotus maximus*), an ostracod, or seed shrimp (*Cypris pellucida*), and an amphipod, or scud (*Hyalella azteca*). Among rotifers, two species (*Brachionus satanicus*, *Pedalia fennica*) occurred periodically in “great numbers.” Rotifers *Brachionus satanicus*, *B. spatiosus*, and *B. pterodinooides* were described by Young as new species. Cladocerans occurred “infrequently,” while copepods were extremely abundant; Young observed that a large area of the lake was once “literally colored red” by “great masses” of the copepod *Diaptomus* sp.

Although aquatic insects had been collected between 1909 and 1923, insect identifications and life-history research had not yet been completed when Young published his book. He reported that knowledge about Devils Lake insects in 1924 was “only a beginning.” Generally, insect species in Devils Lake were relatively few, but most of those were highly prolific. Chironomids, or midge flies (*Chironomus* sp., *Protenthes* sp.) greatly predominated the insect fauna, their summertime abundance described as “evening swarms that fill the air.” Other dipterans included soldier flies, horseflies, deer flies, and flower flies (“rat-tailed maggots”). Among beetles, six genera and two species had been identified. Dragonflies and damselflies consisted of “several species,” none of which were listed. Water boatmen (Corixidae) and back swimmers (Notonectidae) were second to midges in abundance. Among caddis flies, *Limnephilus rhombicus* was the most common.

Invertebrates not found included porifera (sponges), coelenterates (hydroids, jellyfish), nemertean (proboscis worms), annelids (aquatic earthworms, leeches), or bryozoans (moss animalcules). Among insects, stoneflies (Plecoptera), mayflies (Ephemeroptera), spongilla flies (Neuroptera), and aquatic caterpillars (Lepidoptera) were also absent. The lake was devoid of living

mollusks (snails, clams, mussels), although the shoreline was littered with “large numbers” of snail and mussel shells, described by Young as “remains of a former fresh-water fauna.”

Lake algae were dominated by blue-greens (41 species) and diatoms (80 species). Chlorophyta (grass-green) species numbered 35. Three blue-greens (*Coelosphaerium kuetzingianum*, *Nodularia spumigena*, *Lyngbya contorta*) were the most common algal species. Among the diatoms, 46 species were described as freshwater types, four species as brackish types, and four species as “marine” or seawater types. The remaining species were euryhaline, able to tolerate a wide range of salinities. Two new diatoms were discovered and named *Navicula minnewaukonensis* and *Chaetoceros elmoriei*. A filamentous alga, *Cladophora* sp., formed “extensive masses” throughout the littoral zone. Widgeon grass (*Ruppia maritima*) was described as the lake’s “only flowering plant of importance.” In 1916, however, due to an influx of “an abundant supply of fresh water,” sedges (*Cyperus* sp.) and rushes grew profusely across a wide expanse of rehydrated old lake bottom.

The Garrison Diversion Project

In December 1944, Congress passed the Flood Control Act of 1944, which included the Pick-Sloan Plan to divert water from the Missouri River to irrigate drought-stricken farmlands in eastern North Dakota. Passage of Pick-Sloan authorized the U.S. Army Corps of Engineers to construct Garrison Dam on the Missouri River and the U.S. Bureau of Reclamation to develop a system of irrigation canals and intermittent water-storage reservoirs (Figure 9). The plan, renamed the Garrison Diversion Project, called for diverting a portion of water through a permanent feeder canal into Devils Lake to “deepen, flush and desalinate the lake for recreation.” Diversion would raise surface elevation to 1,425 feet amsl (Figure 10) and increase surface area to about 80 square miles. Desalination – resulting in a reduction in the lake’s TDS concentration from about 25,000 ppm to about 900 ppm – would require 10 to 12 years to achieve, assuming that 180,000 acre-feet of water having a TDS concentration of 800 ppm

was diverted to Devils Lake annually (Swenson and Colby 1955).

Considerable opposition to the Garrison Diversion Project eventually developed, particularly from environmental organizations and the Canadian government. In 1973, Canada sent a diplomatic note to the U.S. State Department requesting an “immediate stop” to Garrison construction, claiming that the project would violate the 1909 Boundary Waters Treaty by polluting the waters of the Souris and Red rivers which flow into Canada. Although partly built at a cost of more than \$1 billion, the project – derided as the “last of the Dust Bowl relics” – was finally shelved in the late 1980s due to funding and environmental constraints. Nature has since more than compensated for the project’s grand design for Devils Lake.

Reopening of the Biological Station and Resumption of Limnological Research

While Garrison Diversion was being planned during the early 1960s, the University of North Dakota received substantial funding from the Office of Water Resources Research, U.S. Department of the Interior, to determine how and to what extent diversion of Missouri River water would possibly affect the limnology of Devils Lake. A second objective was to determine the limnological impacts of untreated sewage, which the City of Devils Lake had discharged into the lake between 1924 and 1958. Staff and graduate students representing the departments of biology, geology, and microbiology formed an interdisciplinary team to study the lake. The biological station, dilapidated after years of neglect, was restored and outfitted with living quarters and laboratory facilities to accommodate field scientists. Research got underway in 1964 and continued until the early 1970s when funding ended and the biological station was again closed.

Limnological surveys indicated that the lake’s biota had changed little between 1924 and 1964. In addition to the brook stickleback, the only other fish species present was the fathead minnow (*Pimephales promelas*), also capable of tolerating salinities exceeding 10,000 ppm. Northern pike (*Esox lucius*) had

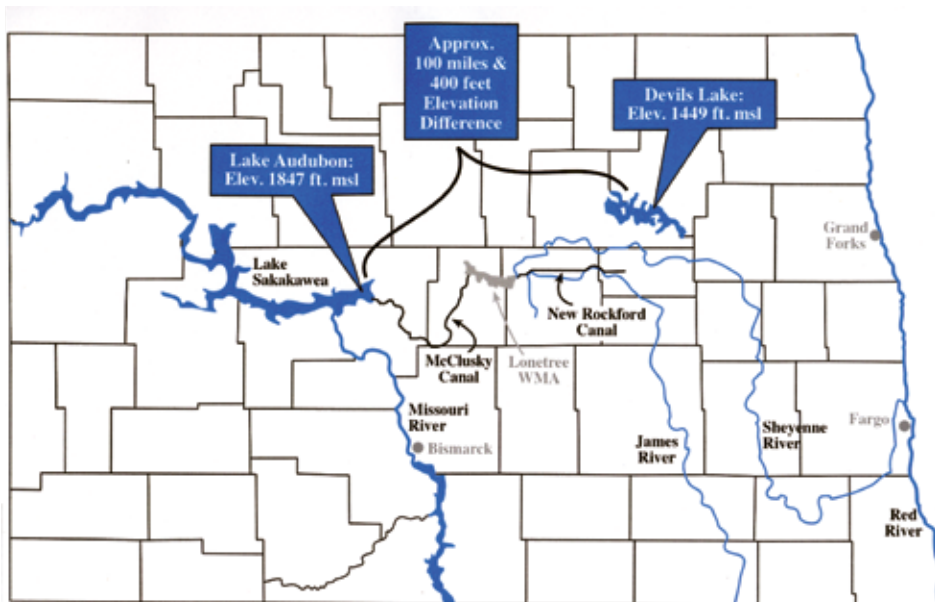


Figure 9. Map of the Garrison Diversion Project, North Dakota. Garrison Dam impounds Lake Sakakawea. Source: North Dakota State Water Commission, Bismarck.



Figure 10. Post marker showing surface elevations of Devils Lake between 1870 and 1910. Elevation 1,425 feet amsl represents lake level under the Garrison Diversion Project. Elevation of Devils Lake (in background) when photo was taken (July 1966) was about 1,413 feet amsl. Photo by the author.

been stocked in the lake by the North Dakota Game and Fish Department beginning in 1956 (1.3 million fingerlings introduced between 1956 and 1969), but this species could not be sustained until the late 1960s (Hiltner 2003), possibly due to high salinity during ice-cover (Scott and Crossman 1973).

The lake's amphibian assemblage remained at two species, the pickerel frog

and the tiger salamander. Salamander larvae were mostly neotenic and relatively large, ranging in total length from 7.6 to 15.2 inches (mean=10.1 inches, n=517). Larvae were also extremely abundant: In October 1964, nearly 6,000 individuals were trapped in a single hoop-net apparatus set for 72 hours in Creel Bay (Larson 1968). The prevalence of neotenic larvae was attributed, hypothetically, to

the lack of density-dependent factors such as predation and interspecific competition (Larson 1968). During the late 1960s, however, as highly predaceous northern pike became reestablished in the lake, salamander larvae probably became major sources of prey.

Invertebrate studies focused on crustaceans and insects. Among zooplankton, copepods greatly outnumbered cladocerans, with copepods dominated by *Diatomus sicilis* and cladocerans by *Moina macrocopa*. Rotifers were comprised of "several" species, two of which (*Brachionus satanicus*, *Pedalia fennica*) were most common (Anderson 1969). Amphipods included *Hyaella azteca* and *Gammarus pseudolimnaeus*. Chironomids completely dominated the macrobenthic fauna; nine chironomid species comprised over 98 percent of the macrobenthic organisms in the sublittoral zone, and over 90 percent in the littoral zone. Among chironomids, *Tanytus nubifer* was most abundant (95 percent of total organisms), followed by *Chironomus decorus* (4 percent). The maximum density of *T. nubifer* (25,324 individuals/meter²) attested to the prodigious production capacity of chironomids in Devils Lake, particularly in Creel Bay where 34 years of untreated sewage disposal greatly enriched sediments with organic matter and nutrients (Knauss 1970).

Despite high production by chironomids, phytoplankton primary production (ppn) in Devils Lake was indicative of a mesotrophic system. Mean annual productivity over a three-year period (1966-1968) ranged from 420 to 800 mg C/meter²/day (Anderson 1969), roughly within the mesotrophic range (210-729 mg C/meter²/day) cited by Wetzel (1983, pages 398-399). But Anderson (1969) also reported a maximum ppn rate of 5,140 mg C/meter²/day, which, according to Wetzel's classification, would have easily qualified Devils Lake as eutrophic.

Heavy growths of filamentous algae, *Cladophora glomerata* and *Enteromorpha prolifera*, clogged near-shore waters in Creel Bay (Figure 11). Dense clusters of *Ruppia maritima* (widgeon grass) and *Potamogeton pectinatus* (sago pondweed) occurred intermittently along the lake's entire beaches (Knauss 1970).



Figure 11. Dr. David Anderson, University of North Dakota, displays mass of filamentous algae in Creel Bay near the biological station. Photo by the author, August 15, 1968.

In winter, extremely low air temperatures (typically -20°F and lower) produced surface ice layers that were 3 to 4 feet thick. Freezing caused lake-water salts to concentrate, resulting in TDS concentrations ranging between 16,000 and 18,000 ppm. When ice-free, the lake was considerably less saline; summertime TDS concentrations were usually around 12,000 ppm (Anderson 1969).

The Life of Devils Lake: 2004

By 2004, Devils Lake was about 35 feet deeper, more than five times larger in area, and nearly 10 times less saline than it had been in 1924. Elstad (2002) described the lake as “hypereutrophic” because of substantial nutrient enrichment causing “prolific” blue-green algal blooms. Between 1995 and 2001, sample concentrations for total phosphorus ranged between 180 and 950 micrograms/liter (parts per billion), with the highest value falling well within the range cited by Wetzel (1983, page 293) for hypereutrophic lakes. Sample concentrations for chlorophyll-*a* (10-30 micrograms/liter) were more typical of eutrophic lakes (3-78 micrograms/liter on Wetzel’s scale).

Agricultural runoff (fertilizers, animal wastes) was and still is a major source of nutrient loading, particularly during spring snowmelt; approximately 88

percent of the Devils Lake watershed is used for agricultural (Hiltner 2003). Other nutrient sources include wastewater from sewage stabilization ponds and nutrients released from agricultural lands inundated by rising lake waters.

Devils Lake is currently the “number two” fishery in North Dakota (Hiltner 2003), second only to giant Lake Sakakawea behind Garrison Dam on the Missouri River. The lake is known locally as “the perch capital of the world.” Since 1956, the North Dakota Game and Fish Department has stocked the lake with nearly 65 million fish, mostly fingerlings. Roughly 68 percent of these fish were wall-eyed pike, followed by yellow perch (18 percent), and northern pike (14 percent). Other species introduced included muskellunge (228,000), striped bass (13,000), black crappie (4,500), and about 600 white bass (Hiltner 2003).

Flood Control

As it expanded, Devils Lake inundated thousands of acres of valuable agricultural land, dozens of farmsteads, three state parks, miles of paved highways and roads (Figure 12), railroad tracks (Figure 13) and an estimated half-million trees (Figure 14). As many as 400 rural families were forced to move their homes away from steadily advancing lake waters. Several farmsteads were

left stranded on an island created by the rising water. Residents in the town of Minnewaukan, who once viewed the lake from a considerable distance, now found themselves at the water’s edge (refer back to Figure 5).

To protect the city of Devils Lake from the encroaching lake, the Army Corps of Engineers designed and constructed a \$50-million dike during the 1990s that stretches for about seven miles along the southern and western edges of the city (Figure 15; also refer back to Figure 6). The dike, consisting of gravel and clay overlaid by boulders (Figure 16), was built to an elevation of 1,457 feet amsl. The Corps of Engineers certified that the dike would provide flood protection to a lake level of 1,450 feet amsl. But as the lake continued to rise, reaching elevation 1,449.2 feet amsl in May 2006, the Corps raised the dike’s crest another three feet, to elevation 1,460 feet amsl, at a cost of about \$8 million. If the lake were to rise above elevation 1,454 feet amsl – the current level of protection – the dike would need to be raised further. Relief would finally come at elevation 1,459 feet amsl when the lake would begin draining naturally into the Sheyenne River, an event that has occurred only three times over the past roughly 4,000 years.

Plans were also made to slow or halt the lake’s continued rise by drawing it down. In 2001, the North Dakota Legislature authorized the construction of an emergency outlet through which water would be pumped from Devils Lake into the Sheyenne River. Given the cost of the outlet project (\$185 million based on estimates by the Corps of Engineers), North Dakota officials decided that the State of North Dakota should build the outlet, albeit a considerably downsized, and thus cheaper, version than the one recommended by the Corps.

Like the Garrison Diversion Project earlier, the Devils Lake outlet plan was controversial. Proponents of the project estimated that the outlet, under a “wet scenario,” would remove about 170,000 acre-feet of water over a ten-year period, resulting in a total drawdown of about 17 inches. Other estimates were more optimistic, claiming that the drawdown could be as much as four inches per year. Outlet opponents disagreed, arguing



Figure 12. Aerial view of Devils Lake's West Bay. The town of Minnewaukan appears in the upper left-hand corner of the photo. U.S. Highway 281 proceeds north out of Minnewaukan and crosses the west end of the lake before intersecting with State Highway 19 and continuing north. U.S. Highway 281 was kept open by raising the roadbed and riprapping its shoulders. The highway was later relocated farther west, away from the lake. Photo by the author, October 9, 2004.



Figure 13. Tracks of the former Northern Pacific Railway lie partly submerged along the north shore of Devils Lake. Photo by the author, October 6, 2004

that the lake would continue to rise if inflows like those measured between 1993 and 2000 (averaging 317,000 acre-feet annually) recurred.

Opponents also argued that lake waters discharged through the outlet could introduce potentially harmful biota (microorganisms, invasive species) and pollutants (agricultural pesticides,

herbicides, organic wastes) downstream into the Sheyenne River. Contaminants would eventually reach Canada, via the Red River of the North, which empties into Manitoba's Lake Winnipeg.

Fearing environmental damage to their waters, the Canadian government, the State of Minnesota, and nine other states that border the Great Lakes stood

opposed to the outlet. In July 2003, then U.S. Secretary of State Colin Powell wrote a letter to various federal agencies discussing "unresolved environmental concerns" involving the 1909 Boundary Waters Treaty between the U.S. and Canada (*Grand Forks Herald*, August 26, 2007). Despite intensive lobbying by the Canadian Government and others, along with two legal challenges, the Bush Administration and the U.S. Congress refused to block the project. A non-binding agreement was finally reached between the Canadian government and the U.S. to build the project, although Canada required that the outlet be equipped with a filter to prevent harmful biota and pollutants from entering the Sheyenne River. Although Canada agreed to pay \$25 million for a sophisticated sand filter, the State of North Dakota installed a simple rock filter costing \$50,000. The effectiveness of the filter would later be questioned.

Construction of the outlet was completed during the summer of 2005 at a cost of nearly \$30 million. Yearly operational costs were estimated at \$800,000. Since the outlet was not a federal project, an environmental impact statement was not required. When possible, water is pumped at the rate of 100 cubic feet per second through a 14-mile-long outlet channel that empties into the Sheyenne River. The channel's intake is located near the town of Minnewaukan (refer back to Figure 3).

The outlet began operating in August 2005. Outlet pumps operated for 11 days in August 2005, discharging about 38 acre-feet of water before the project was shut down for the remainder of the year. In 2006, the outlet was shut down for the entire year because sulfate concentrations in discharge waters (600-800 ppm) violated North Dakota's pollution discharge permit for sulfate set at 450 ppm. In 2007, the outlet was operated for about a month, discharging about 300 acre-feet of water.

Concluding Remarks

Young (1924) predicted that Devils Lake would "probably disappear during the next forty or fifty years," assuming that climatic conditions of the 1920s would continue. But the lake was nearly gone after only 16 years and would have



Figure 14. Aerial view of State Highway 57 (SH57), which extends from upper right-hand corner of photo to an island in the lower left-hand corner. SH57 separates Main Bay (left side) from East Bay (right side). Spirit Lake Casino and Resort, complete with boat marina and wastewater stabilization ponds, occupies the island. Portions of the island's forest are partly submerged offshore. State Highway 20 extends from lower right-hand corner of photo to junction with SH57. Sixmile Bay is visible at top of photo. Creel Bay extends north from Main Bay. Photo by the author, October 9, 2004.



Figure 15. Aerial view of the City of Devils Lake and the protective dike. Photo by the author, October 9, 2004.

disappeared completely had it not been for a slow but steady improvement in North Dakota's moisture conditions beginning in 1941. In 1974, 50 years after Young's dire prediction, Devils Lake had instead risen about seven feet – to elevation 1,423 feet amsl – and covered about 71 square miles, nearly twice the area it had covered in 1924. Few would have predicted what the lake has become over the past 30 years, a rising prairie sea that has flooded not the entire world – but a sizeable portion of northeastern North Dakota.

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Figure 16. Protective dike, ground level. Photo by the author, October 6, 2004.

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