VARIATIONS IN SURFACE-WATER QUANTITY AND QUALITY AS A RESULT OF THE 1993 SUMMER FLOOD IN THE DEVILS LAKE BASIN, NORTH DAKOTA

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre-foot	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
inch	25.4	millimeter
kilogram	2.205	pound
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 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 µg/L.

Variations in Surface-Water Quantity and Quality as a Result of the 1993 Summer Flood in the Devils Lake Basin, North Dakota

By Tara Williams-Sether, Robert M. Lent, *and* Gregg J. Wiche

Abstract

Greater-than-normal precipitation during the summer of 1993 affected the hydrologic response and surface-water quality in the Devils Lake Basin. Large areas in the basin were flooded as a result of the precipitation, and water from these areas drained slowly through the chain of lakes into Devils Lake. This report summarizes the results of surface-water quantity and quality monitoring designed to document the effects of flooding in the Devils Lake Basin. Specific objectives are (1) to document the quantity and quality of streamflow in the Devils Lake Basin immediately before, during, and after the 1993 flood and (2) to document the hydrologic and chemical changes in the upstream chain of lakes and in Devils Lake during April through October 1993.

Precipitation during June through August ranged from about 17 inches in the Mauvais Coulee subbasin to about 21.4 inches in the Edmore Coulee subbasin. Streamflow measured for Edmore Coulee Tributary indicated that 12.2 inches of runoff occurred during April through October 1993. This is one of the greatest runoffs in North Dakota for which records are available.

During April through September, the cumulative volume of inflow to the chain of lakes was about 8 percent of the cumulative volume of rainfall and the measured cumulative volume of outflow from the chain of lakes was about 7 percent of the cumulative volume of rainfall. The cumulative volume of water stored in the chain of lakes increased from 6,350 acre-feet in April to 82,300 acre-feet in August and then decreased to 24,400 acre-feet in October. Devils Lake rose from 1,423.0 feet above sea level on June 10 to 1,427.0 feet above sea level on September 28, largely in response to direct precipitation on the lake.

Nutrient concentrations for coulees that flow into the chain of lakes generally were at a maximum during the spring and a minimum during the late summer and fall. About 37 percent of the dissolved-solids load and about 43 percent of the total ammonia plus organic nitrogen load was attributed to Edmore Coulee Tributary. Between May and October, increases in the total ammonia plus organic nitrogen mass for the chain of lakes ranged from about 39 to 133 percent. Increases in the total phosphorus mass ranged from about 43 to 157 percent.

Decreases in dissolved-solids concentrations from May to early August ranged from about 77 percent in Sixmile Bay to about 9 percent in Main Bay, Creel Bay, and East Devils Lake. Decreases in the dissolved-solids concentrations in Devils Lake and East Devils Lake may have been the result of dilution by direct precipitation. However, during the same period, dissolved-solids concentrations increased about 6 percent in East Bay.

Between May and October, the dissolved-solids mass for Devils Lake and East Devils Lake increased 500 million kilograms. Only about 25 percent of the increase can be attributed to streamflow. The total ammonia plus organic nitrogen mass for Devils Lake and East Devils Lake increased about 38 percent between May and October, and the total phosphorus mass increased about 79 percent.

INTRODUCTION

Greater-than-normal precipitation during the summer of 1993 caused severe flooding in a nine-state area, including North Dakota. Large areas of farmland north and northeast of Devils Lake (fig. 1) were flooded as a result of the precipitation, and water from these areas drained slowly through the chain of lakes into Devils Lake. The level of Devils Lake rose from 1,423.0 feet above sea level on June 10 to 1,424.4 feet above sea level on July 31, largely in response to direct precipitation on the lake. Large streamflow volumes from Big Coulee and Channel A after July 31 caused the lake to rise to 1,427.0 feet above sea level by September 28. The 1993 flood increased the volume of water in Devils Lake by about 300,000 acre-feet; previously recorded summer floods (late 1800's-1993) had increased the volume of water in the lake by no more than 30,000 acre-feet.

The Devils Lake Basin has been a popular recreational area during the last 110 years, and Devils Lake has been the main attraction for much of the recreation. Unlike many terminal lakes, Devils Lake has been a productive sport fishing lake intermittently since settlers arrived in the early 1880's. Recreational and fishery values of Devils Lake are closely associated with water-level fluctuations of the lake. Rising water levels from about 1969 through 1987 resulted in an increase in recreational activity (especially fishing) and tourism. Declining water levels from 1987 through 1992 threatened recreational activity and 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. Concerns about declining water levels and potential fish kills have been reduced temporarily by the greater-than-normal precipitation during the summer of 1993.

This report, prepared in cooperation with the North Dakota Department of Health, summarizes the results of surface-water quantity and quality monitoring designed to document the effects of flooding in the Devils Lake Basin in 1993. Specific objectives of the report are (1) to document the quantity and quality of streamflow in the Devils Lake Basin immediately before, during, and after the 1993 flood (April through October) and (2) to document the hydrologic and chemical changes in the upstream chain of lakes and in Devils Lake during April through October 1993.

Description of Study Area

The Devils Lake Basin, in northeastern North Dakota, is a 3,810-square-mile closed basin in the drainage of the Red River of the North (fig. 1). Numerous shallow depressions and potholes occur throughout the Devils Lake Basin. Many of these depressions are connected by poorly defined channels and swales. About 3,310 square miles of the total 3,810 square miles is tributary to Devils Lake, the terminal lake within the Devils Lake Basin. Before 1979, streamflow from Edmore, Starkweather, Calio, Mauvais, and Little Coulees flowed through the "chain of lakes" (consisting of, in downstream order, Sweetwater Lake, Morrison Lake, Cavanaugh Lake, Dry Lake, Mikes Lake, Chain Lake, Lake Alice, and Lake Irvine) into Big Coulee, which was the only principal stream flowing directly to Devils Lake (fig. 1). In 1979, the Ramsey County and Cavalier County Water Management Boards completed construction of

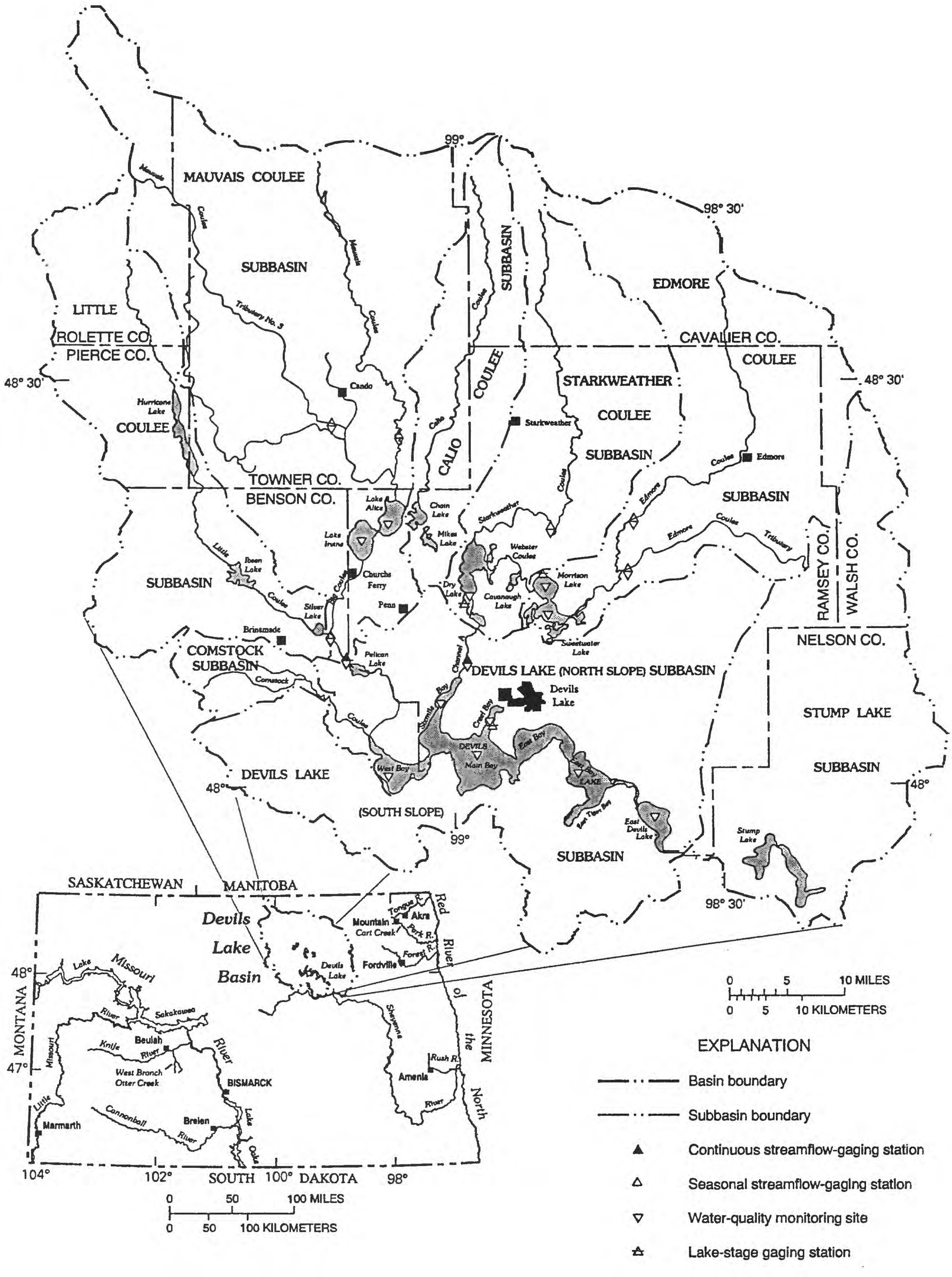

Figure 1. Location and major features of the Devils Lake Basin.

Channel A, which connects Dry Lake to Sixmile Bay of Devils Lake. Streamflow from Sweetwater, Morrison, and Dry Lakes now is conveyed to Devils Lake by Channel A, and the remaining streamflow from other sources follows the natural watercourse (Wiche and others, 1986).

The Devils Lake Basin consists of nine subbasins (fig. 1). Of these subbasins, eight contribute to Devils Lake and one contributes to Stump Lake. Of the eight subbasins that contribute to Devils Lake, two northeastern subbasins (Edmore Coulee and Starkweather Coulee) provide streamflow to Channel A; three northwestern subbasins (Calio Coulee, Mauvais Coulee, and Little Coulee) provide streamflow to Big Coulee; and the remaining three subbasins [Comstock, Devils Lake (North Slope), and Devils Lake (South Slope)] provide streamflow directly to Devils Lake. Big Coulee and Channel A are the main sources of surface water to Devils Lake. Devils Lake consists of five bays, which are, from west to east, West Bay, Sixmile Bay, Main Bay, Creel Bay, and East Bay (fig. 1). Devils Lake is connected to East Devils Lake at a water level of about 1,425.0 feet above sea level.

The water budget of Devils Lake is largely dependent upon recent climatic conditions. Water enters Devils Lake by precipitation onto the lake surface and by inflow of surface water and ground water. The contribution by ground-water inflow, however, is small compared to the contribution by surface-water inflow and precipitation (Pusc, 1993). Water is removed from the lake only by evaporation; therefore, there are no outlets for the dissolved solids and nutrients. As a result, Devils Lake is saline and nutrient rich (Lent, 1994).

Methods of Data Collection and Analysis

Monthly precipitation values for the Devils Lake Basin for April through September 1993 were obtained from the North Dakota Atmospheric Resource Board (written commun., 1994). An isohyetal method (Linsley and others, 1982) was used to calculate area-weighted monthly mean precipitation for the nine subbasins in the Devils Lake Basin. Precipitation stations that had incomplete records were not used in the calculations. The number of stations used for the nine subbasins varied from month to month and ranged from 47 to 64. Monthly volumes of rainfall were calculated by multiplying the mean monthly precipitation value by the subbasin drainage area.

Streamflow was measured and water-quality samples were collected at seasonal (March through September) streamflow-gaging stations on Edmore Coulee, Edmore Coulee Tributary, Starkweather Coulee, Mauvais Coulee, Mauvais Coulee Tributary No. 3, and Little Coulee and at continuous streamflow-gaging stations on Big Coulee and Channel A (fig. 1). Measurements were made and samples were collected according to standard U.S. Geological Survey methods. Water samples were collected using the Equal-Transit Rate method (Guy and Norman, 1970). Water samples collected for nutrient determinations were analyzed at the U.S. Geological Survey National Water Quality Laboratory in Arvada, Colo., and water samples collected for major-ion determinations, which were used to calculate dissolved-solids concentrations, were analyzed at the North Dakota State Water Commission laboratory in Bismarck, N. Dak.

Dissolved-solids concentrations were calculated by summing calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, and silica concentrations. The effects of carbon dioxide degassing and gypsum hydration were not included.

Lake-stage data were collected at continuous lake-stage gaging stations at Devils Lake, Morrison Lake, and Dry Lake. Intermittent staff-gage data were collected at Lake Alice and Lake Irvine by the U.S. Geological Survey and the U.S. Fish and Wildlife Service. To adequately represent quality through the total lake depth, water samples were taken at numerous depths from Sweetwater Lake, Morrison Lake, Dry Lake, Lake Alice, Lake Irvine, Devils Lake, and East Devils Lake (fig. 1) using a Kemmerer bottle and composited in a churn splitter. Water samples collected for nutrient determinations were analyzed at the U.S. Geological Survey National Water Quality Laboratory in Arvada, Colo., and water samples collected for major-ion determinations were analyzed at the North Dakota Department of Health in Bismarck, N. Dak.

Hydrographs for all coulees and channels used in this study were segmented on the basis of distribution of water-quality samples. The volume of streamflow for each segment was calculated by summing the daily volumes of streamflow. Dissolved-solids and selected nutrient loads for the individual hydrograph segments were calculated by multiplying the volume of streamflow by the constituent concentration. If the constituent concentration was less than the detection level, the concentration was set at the detection level for computation purposes. The volume of water in each of the various lakes and bays used in this study was taken from elevation-capacity tables (Dale Frink, North Dakota State Water Commission, written commun., 1993; Clarke Dirks, U.S. Fish and Wildlife Service, written commun., 1994). Dissolved-solids and selected nutrient masses for the lakes and bays were calculated by multiplying the volume of water by the constituent concentration. Rigorous statistical methods were not used to determine nutrient loads and masses because unusual flow conditions in the Devils Lake Basin resulted in a limited amount of data.

Volumes of measured inflow and outflow were calculated by converting streamflow in cubic feet per second to streamflow in acre-feet for a particular time period. Estimated volumes of outflow were calculated using

$$O_{est} = I - \Delta S$$

where

O_{est} is the estimated volume of outflow, in acre-feet;

I is the inflow, in acre-feet; and

ΔS is the change in lake storage in the subbasin, in acre-feet.

Effects of evapotranspiration were not accounted for because of lack of data.

CLIMATIC AND ANTECEDENT HYDROLOGIC CONDITIONS

The midwestern United States experienced one of the most severe floods on record during June and July 1993. The region of extensive flooding encompassed parts of nine states, including eastern North Dakota. Three environmental factors played a major role in the formation, duration, and intensity of the Midwest flood (Halpert and others, 1994). The first factor was the greater-than-normal soil moisture that preceded the onset of the flood; the second factor was a persistent, anomalous atmospheric circulation over North America that allowed moist, tropical air to interact with a vigorous storm track over the midwestern United States; and the third factor was the repetition of excessive, focused rainfall during June and July.

Topsoil moisture in the Devils Lake Basin was adequate during April through June, became surplus during July and August, and returned to adequate during September and October. Storage capacities of wetlands varied across the basin (North Dakota Agricultural Statistics Service, 1993). Most permanently flooded wetlands were full after the spring snowmelt; thus, storage capacity was limited and the potential for runoff from precipitation increased. Temporarily and seasonally flooded wetlands had been cropped and were available for storage in the event of excessive rainfall. Vegetation growth within the coulees in the basin was extensive and created the potential for slow recession of floodwater.

Precipitation at the city of Devils Lake was near normal during April and May (table 1). Precipitation during June and July was about 16.5 inches, about 10.5 inches greater than normal. Almost 9 inches of the

July precipitation fell between July 14 and 28. Precipitation during August was 2.29 inches, 0.22 inches greater than normal, and precipitation during September and October was 0.47 inches, 2.61 inches less than normal.

Table 1. *Monthly precipitation at the city of Devils Lake for April through October 1993 and mean monthly precipitation for 1961-90*

Period	Precipitation (inches)							
	April	May	June	July	August	September	October	Total for April through October
1993	0.87	2.21	6.16	10.3	2.29	0.17	0.30	22.3
1961-90[1]	1.07	2.13	3.35	2.66	2.07	1.95	1.13	14.4

[1]Data from Owenby and Ezell (1992).

Precipitation was not distributed equally throughout the Devils Lake Basin. Mean monthly precipitation for the nine subbasins in the Devils Lake Basin is shown in table 2. During June through August, the Edmore Coulee subbasin received about 21.4 inches of precipitation, an average of about 2.63 inches more than the other subbasins. The variability of precipitation in the Devils Lake Basin during July is shown in figure 2. Total precipitation during July ranged from about 6 inches to more than 13 inches.

Table 2. Mean monthly precipitation for subbasins in the Devils Lake Basin for April through October 1993

[Area-weighted mean monthly precipitation was calculated from monthly precipitation values obtained from the North Dakota Atmospheric Resource Board (written commun., 1994); --, no data; the North Dakota Atmospheric Resource Board collects data only during April through September]

Subbasin	Precipitation (inches)						
	April	May	June	July	August	September	October
Edmore Coulee	0.34	3.25	7.65	10.3	3.46	0.86	--
Starkweather Coulee	.38	2.66	7.66	8.08	3.41	.87	--
Calio Coulee	.35	2.37	7.35	7.21	3.13	.69	--
Mauvais Coulee	.57	2.68	6.11	7.77	3.09	.75	--
Little Coulee	1.01	2.34	6.02	8.75	2.84	.36	--
Comstock	.93	2.75	7.53	9.36	1.91	.24	--
Devils Lake (North Slope)	.58	3.13	7.69	9.30	2.99	.45	--
Devils Lake (South Slope)	.99	3.06	7.24	10.5	1.98	.30	--
Stump Lake	.44	3.44	6.81	9.44	4.10	.33	--

SURFACE-WATER QUANTITY IN THE DEVILS LAKE BASIN DURING 1993

Upstream of the Chain of Lakes

Streamflow from upstream of the chain of lakes is provided by four main subbasins. These are, from east to west, Edmore Coulee, Starkweather Coulee, Calio Coulee, and Mauvais Coulee. Streamflow was

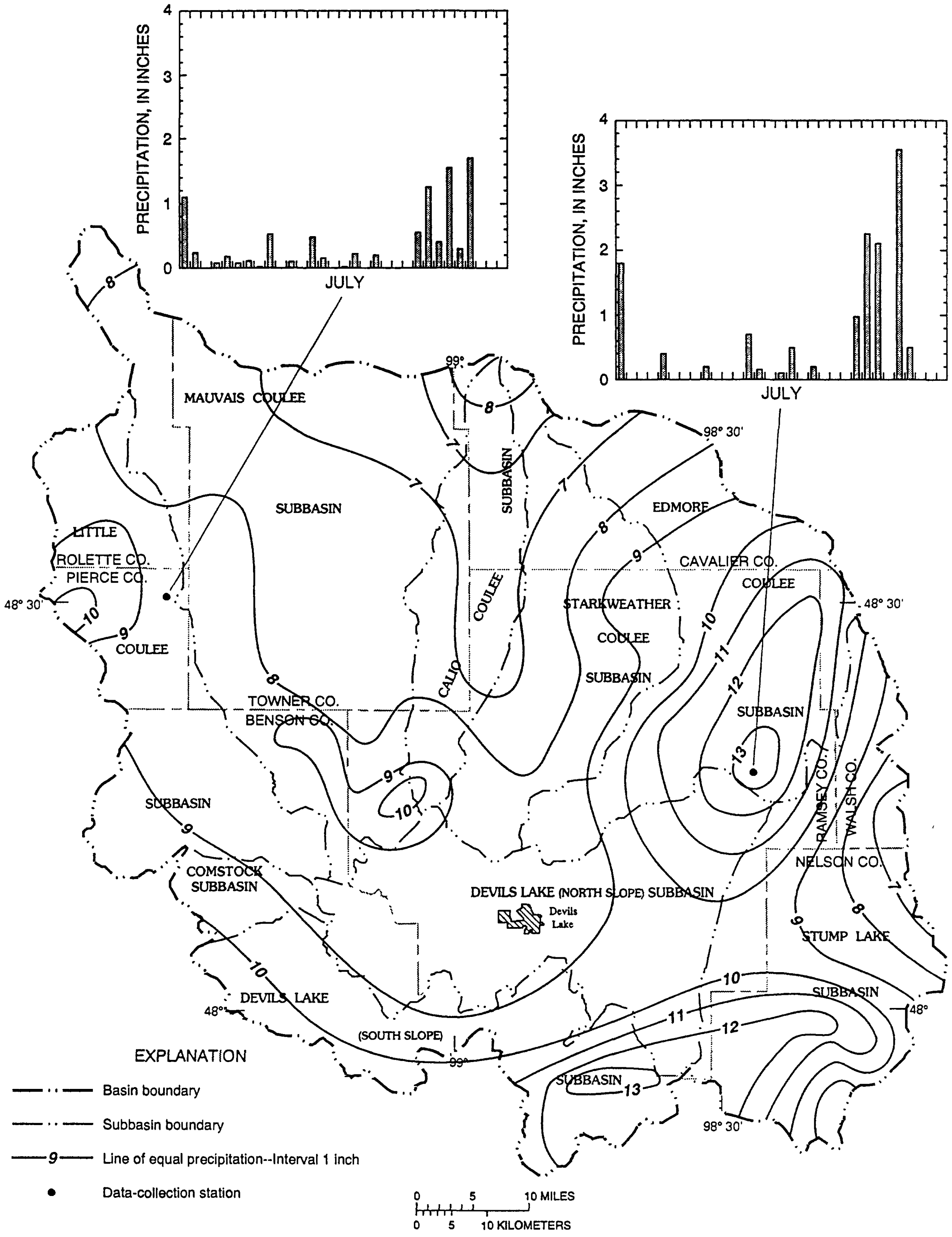

Figure 2. Precipitation in the Devils Lake Basin, July 1993. (Data from North Dakota Atmospheric Resource Board, written commun., 1994.)

measured at five streamflow-gaging stations on Edmore Coulee, Edmore Coulee Tributary, Starkweather Coulee, Mauvais Coulee, and Mauvais Coulee Tributary No. 3 during April through October (fig. 1).

Runoff from spring snowmelt caused an increase in streamflow at all five gaging stations during the first 2 weeks in April (figs. 3, 4, and 5). Maximum streamflow during the snowmelt period was 318 cubic feet per second on April 10 in Edmore Coulee, 160 cubic feet per second on April 7 in Edmore Coulee Tributary, 220 cubic feet per second on April 13 in Starkweather Coulee, 99 cubic feet per second on April 10 in Mauvais Coulee, and 15 cubic feet per second on April 10 in Mauvais Coulee Tributary No. 3.

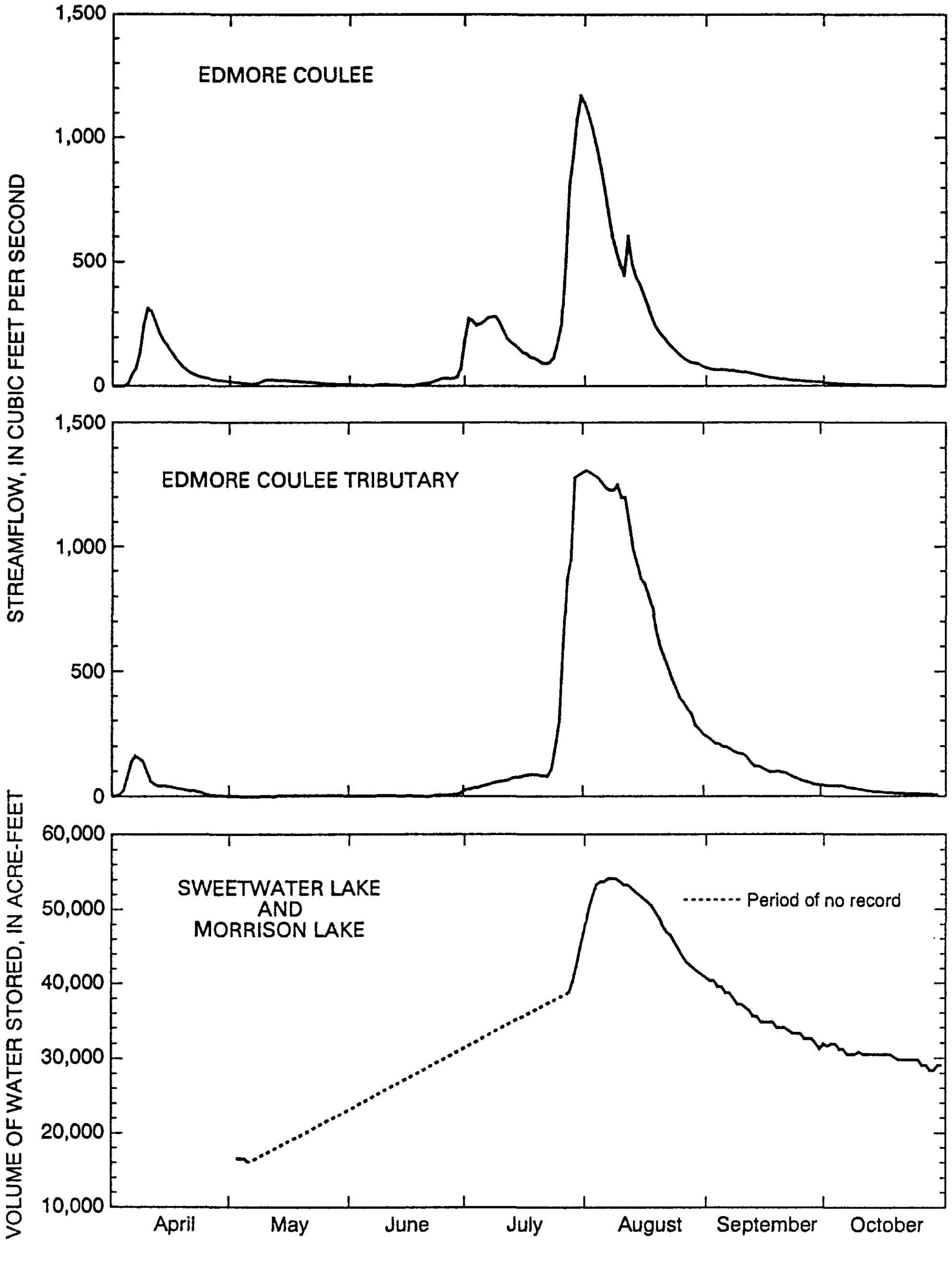

Figure 3. Streamflow in Edmore Coulee and Edmore Coulee Tributary and volume of water stored in Sweetwater Lake and Morrison Lake combined, April through October 1993.

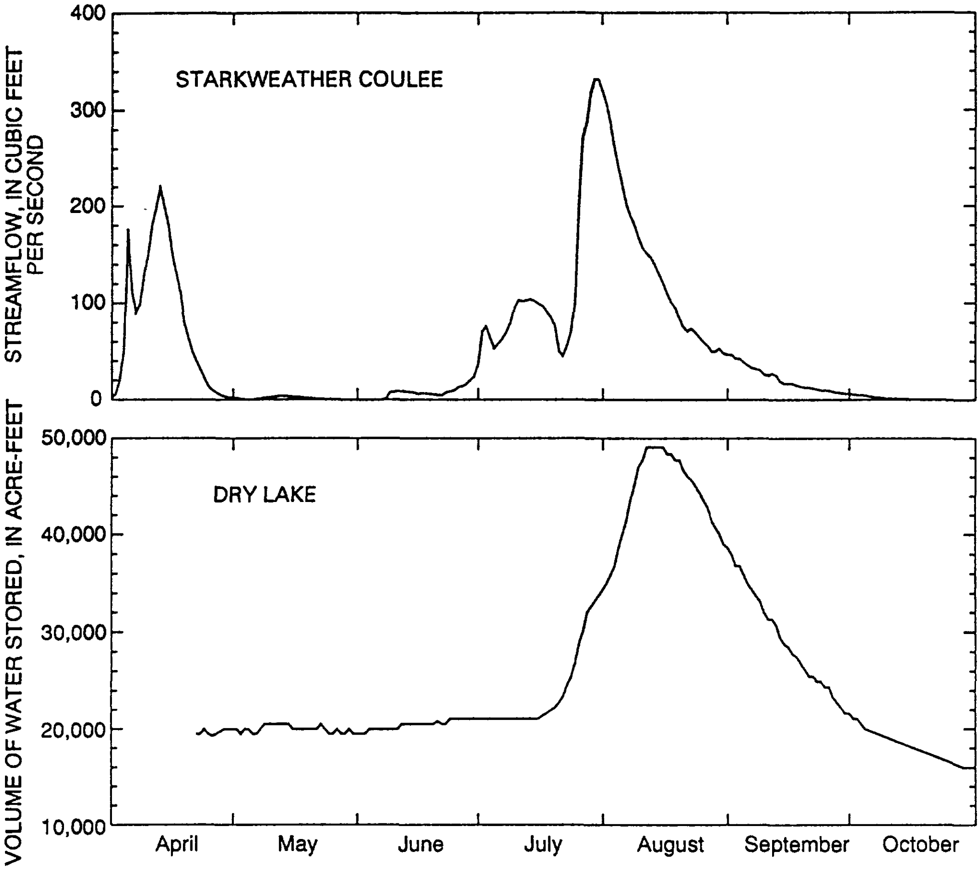

Figure 4. Streamflow in Starkweather Coulee and volume of water stored in Dry Lake, April through October 1993.

Several intense rainfalls during June and July also caused an increase in streamflow at all five gaging stations. Maximum daily streamflow was 1,170 cubic feet per second on July 31 in Edmore Coulee, 1,310 cubic feet per second on August 2 in Edmore Coulee Tributary, 332 cubic feet per second on July 30 and 31 in Starkweather Coulee, 696 cubic feet per second on August 2 in Mauvais Coulee, and 244 cubic feet per second on August 2 in Mauvais Coulee Tributary No. 3. A peak of record of 1,180 cubic feet per second occurred on Edmore Coulee on July 30, and a peak of record of 1,330 cubic feet per second occurred on Edmore Coulee Tributary on August 2. These peaks occurred as a result of the intense rainfalls. On October 31, streamflow was 1.30 cubic feet per second in Edmore Coulee, 8.10 cubic feet per second in Edmore Coulee Tributary, 11.0 cubic feet per second in Mauvais Coulee, and 0.24 cubic feet per second in Mauvais Coulee Tributary No. 3. Starkweather Coulee had no flow on October 31.

Chain of Lakes

Sweetwater Lake and Morrison Lake are located in the Edmore Coulee subbasin. Edmore Coulee is the primary source of water to Sweetwater Lake, which flows into Morrison Lake. Outflow from Morrison Lake enters Dry Lake via Webster Coulee. The cumulative volume of rainfall in the Edmore Coulee subbasin during April through September was 660,000 acre-feet (table 3). The cumulative volume of inflow to Sweetwater Lake was about 20 percent of the cumulative volume of rainfall and the estimated cumulative volume of outflow from the subbasin was about 18 percent of the cumulative volume of rainfall. From May through October, the cumulative volume of water stored in Sweetwater Lake and Morrison Lake combined increased 6,600 acre-feet. The cumulative volume of inflow to Sweetwater Lake from Edmore Coulee and Edmore Coulee Tributary during April through October was 135,000 acre-feet.

The estimated cumulative volume of outflow from Morrison Lake to Webster Coulee was 122,000 acre-feet. During July, the cumulative volume of rainfall in the Edmore Coulee subbasin increased 265,000 acre-feet, the cumulative volume of inflow to Sweetwater Lake and Morrison Lake increased 32,800 acre-feet, the estimated cumulative volume of outflow from the Edmore Coulee subbasin increased about 17,400 acre-feet, and the cumulative volume of water stored in Sweetwater Lake and Morrison Lake increased 15,300 acre-feet. During August, the cumulative volume of rainfall in the Edmore Coulee subbasin increased 87,000 acre-feet, the cumulative volume of inflow to Sweetwater Lake and Morrison Lake increased 79,600 acre-feet, the estimated cumulative volume of outflow from the Edmore Coulee subbasin increased 83,600 acre-feet, and the cumulative volume of water stored in Sweetwater Lake and Morrison Lake decreased 3,900 acre-feet.

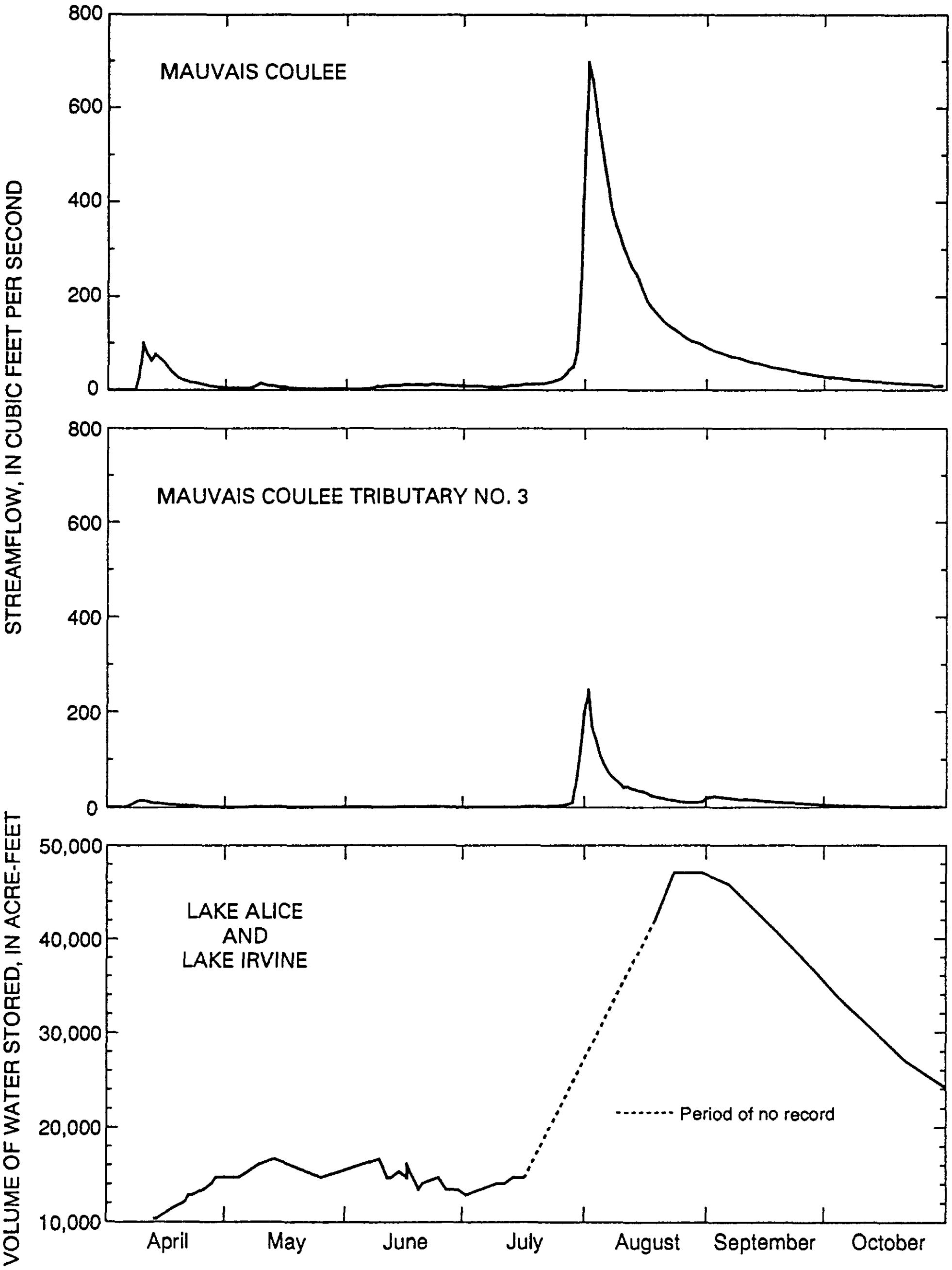

Figure 5. Streamflow in Mauvais Coulee and Mauvais Coulee Tributary No. 3 and volume of water stored in Lake Alice and Lake Irvine combined, April through October 1993.

Table 3. Cumulative volume of rainfall, cumulative volume of inflow, estimated and measured cumulative volumes of outflow, and cumulative volume of water stored in Edmore Coulee subbasin, Starkweather Coulee subbasin, Calio Coulee subbasin, and Mauvais Coulee subbasin during April through October 1993

[Numbers were rounded after computations; numbers in parentheses are negative; --, no data]

Month	Cumulative volume of rainfall (acre-feet)	Cumulative volume of inflow (acre-feet)	Estimated cumulative volume of outflow (acre-feet)	Measured cumulative volume of outflow (acre-feet)	Cumulative volume of water stored (acre-feet)
		Edmore Coulee subbasin			
April	8,690	[1]8,300	[2]8,300	--	--
May	91,100	[1]9,520	[2]3,620	--	[3]5,900
June	285,000	[1]10,600	[2](2,590)	--	[3]13,200
July	550,000	[1]43,400	[2]14,800	--	[3]28,500
August	637,000	[1]123,000	[2]98,400	--	[3]24,600
September	660,000	[1]134,000	[2]119,000	--	[3]14,600
October	--	[1]135,000	[2]122,000	--	[3]12,500
		Starkweather Coulee subbasin			
April	7,580	[4]13,300	[5]11,300	[6]1,250	[7]2,000
May	61,900	[4]8,740	[5]6,990	[6]1,250	[7]1,750
June	216,000	[4]2,950	[5](153)	[6]2,400	[7]3,100
July	383,000	[4]27,700	[5]11,900	[6]11,500	[7]15,800
August	452,000	[4]120,000	[5]98,700	[6]87,900	[7]21,000
September	469,000	[4]142,000	[5]138,000	[6]129,000	[7]3,650
October	--	[4]146,000	[5]148,000	[6]140,000	[7](2,000)
		Calio Coulee subbasin			
April	4,170	--	--	--	--
May	32,800	--	--	--	--
June	119,000	--	--	--	--
July	206,000	--	--	--	--
August	244,000	--	--	--	--
September	252,000	--	--	--	--
October	--	--	--	--	--
		Mauvais Coulee subbasin			
April	25,700	[8]1,870	[9](2,480)	[10]1,450	[11]4,350
May	145,000	[8]2,250	[9](2,750)	[10]2,840	[11]5,000
June	420,000	[8]2,810	[9](238)	[10]3,950	[11]3,050
July	769,000	[8]4,710	[9](9,640)	[10]7,410	[11]14,300
August	909,000	[8]24,900	[9](11,800)	[10]21,200	[11]36,700
September	943,000	[8]29,100	[9]3,660	[10]39,700	[11]25,400
October	--	[8]30,300	[9]16,400	[10]54,200	[11]13,900

[1]Cumulative volume of inflow from Edmore Coulee and Edmore Coulee Tributary.

[2]Estimated cumulative volume of outflow to Webster Coulee. April estimate based only on cumulative volume of inflow from Edmore Coulee and Edmore Coulee Tributary.

[3]Cumulative volume of water stored in Sweetwater Lake and Morrison Lake combined.

[4]Cumulative volume of inflow from Starkweather Coulee and Webster Coulee.

[5]Estimated cumulative volume of outflow to Channel A.

[6]Measured cumulative volume of outflow to Channel A.

[7]Cumulative volume of water stored in Dry Lake.

[8]Cumulative volume of inflow from Mauvais Coulee and Mauvais Coulee Tributary No. 3.

[9]Estimated cumulative volume of outflow to Big Coulee.

[10]Measured cumulative volume of outflow to Big Coulee.

[11]Cumulative volume of water stored in Lake Alice and Lake Irvine combined.

Dry Lake is located in the Starkweather Coulee subbasin. Starkweather Coulee and Webster Coulee are the primary sources of water to Dry Lake. Outflow from Dry Lake enters Devils Lake via Channel A. The cumulative volume of rainfall in the Starkweather Coulee subbasin during April through September was 469,000 acre-feet (table 3). The cumulative volume of inflow to Dry Lake was about 30 percent of the cumulative volume of rainfall and the measured cumulative volume of outflow from the subbasin was about 28 percent of the cumulative volume of rainfall. About 5 percent of the cumulative volume of rainfall produced the inflow from Starkweather Coulee. Most of the outflow from Dry Lake came from interbasin flow from Morrison Lake via Webster Coulee. From April through October, the cumulative volume of water stored in Dry Lake decreased 4,000 acre-feet. The cumulative volume of inflow to Dry Lake from Starkweather Coulee and Webster Coulee was 146,000 acre-feet. The estimated cumulative volume of outflow from Dry Lake to Channel A was 148,000 acre-feet. The measured cumulative volume of outflow was 140,000 acre-feet. During July, the cumulative volume of rainfall in the Starkweather Coulee subbasin increased 167,000 acre-feet, the cumulative volume of inflow to Dry Lake increased about 24,800 acre-feet, the estimated cumulative volume of outflow from the Starkweather Coulee subbasin increased about 12,100 acre-feet, the measured cumulative volume of outflow from the Starkweather Coulee subbasin increased 9,100 acre-feet, and the cumulative volume of water stored in Dry Lake increased 12,700 acre-feet. During August, the cumulative volume of rainfall in the Starkweather Coulee subbasin increased 69,000 acre-feet, the cumulative volume of inflow to Dry Lake increased 92,300 acre-feet, the estimated cumulative volume of outflow from the Starkweather Coulee subbasin increased 86,800 acre-feet, the measured cumulative volume of outflow from the Starkweather Coulee subbasin increased 76,400 acre-feet, and the cumulative volume of water stored in Dry Lake increased 5,200 acre-feet.

The cumulative volume of rainfall in the Calio Coulee subbasin during April through September was 252,000 acre-feet (table 3). During July, the cumulative volume of rainfall increased 87,000 acre-feet. During August, the cumulative volume of rainfall increased 38,000 acre-feet.

Lake Alice and Lake Irvine are located in the Mauvais Coulee subbasin. Mauvais Coulee is the primary source of water to Lake Alice, which flows into Lake Irvine. Outflow from Lake Irvine enters Devils Lake via Big Coulee. The cumulative volume of rainfall in the Mauvais Coulee subbasin during April through September was 943,000 acre-feet (table 3). The cumulative volume of inflow to Lake Alice was about 3 percent of the cumulative volume of rainfall and the measured cumulative volume of outflow from the subbasin was about 4 percent of the cumulative volume of rainfall. From April through October, the cumulative volume of water stored in Lake Alice and Lake Irvine combined increased 9,550 acre-feet. The cumulative volume of inflow to Lake Alice from Mauvais Coulee and Mauvais Coulee Tributary No. 3 was 30,300 acre-feet. The estimated cumulative volume of outflow from Lake Irvine to Big Coulee was 16,400 acre-feet. The measured cumulative volume of outflow was 54,200 acre-feet. Runoff from ungaged areas downstream of Mauvais Coulee and Mauvais Coulee Tributary No. 3 and overflow from Dry Lake into Mauvais Coulee via Mikes Lake and Chain Lake account for most of the 37,800-acre-foot difference. During July, the cumulative volume of rainfall in the Mauvais Coulee subbasin increased 349,000 acre-feet, the cumulative volume of inflow to Lake Alice and Lake Irvine increased 1,900 acre-feet, the estimated cumulative volume of outflow from the Mauvais Coulee subbasin decreased about 9,400 acre-feet, the measured cumulative volume of outflow from the Mauvais Coulee subbasin increased 3,460 acre-feet, and the cumulative volume of water stored in Lake Alice and Lake Irvine increased about 11,200 acre-feet. During August, the cumulative volume of rainfall in the Mauvais Coulee subbasin increased 140,000 acre-feet, the cumulative volume of inflow to Lake Alice and Lake Irvine increased about 20,200 acre-feet, the estimated cumulative volume of outflow from the Mauvais Coulee subbasin decreased 2,160 acre-feet, the measured cumulative volume of outflow in the Mauvais Coulee subbasin increased about 13,800 acre-feet, and the cumulative volume of water stored in Lake Alice and Lake Irvine increased 22,400 acre-feet.

The cumulative volume of rainfall in the four subbasins (Edmore Coulee subbasin, Starkweather Coulee subbasin, Calio Coulee subbasin, and Mauvais Coulee subbasin) for the entire chain of lakes during April through September was 2,320,000 acre-feet (table 4). The cumulative volume of inflow to the chain of lakes was about 8 percent of the cumulative volume of rainfall and the measured cumulative volume of outflow from the chain of lakes was about 7 percent of the cumulative volume of rainfall. The remaining 93 percent of the cumulative volume of rainfall probably went to storage locations (lakes, ground water, soil, and wetlands) and evapotranspiration. From April through October, the cumulative volume of water stored in the chain of lakes increased about 18,000 acre-feet. The cumulative volume of inflow to the chain of lakes was 188,000 acre-feet. The estimated cumulative volume of outflow from the chain of lakes was 164,000 acre-feet. The measured cumulative volume of outflow was 194,000 acre-feet. The ungaged areas between the streamflow-gaging stations and the chain of lakes account for most of the 30,000-acre-foot difference between the estimated and measured cumulative volumes of outflow from the chain of lakes. During July, the cumulative volume of rainfall in the four subbasins for the entire chain of lakes increased 870,000 acre-feet, the cumulative volume of inflow increased 41,900 acre-feet, the estimated cumulative volume of outflow increased about 2,630 acre-feet, the measured cumulative volume of outflow increased about 12,700 acre-feet, and the cumulative volume of water stored increased 39,400 acre-feet. During August, the cumulative volume of rainfall increased 330,000 acre-feet, the cumulative volume of inflow increased about 108,000 acre-feet, the estimated cumulative volume of outflow increased about 84,700 acre-feet, the measured cumulative volume of outflow increased 90,000 acre-feet, and the cumulative volume of water stored increased 23,600 acre-feet.

Table 4. Cumulative volume of rainfall, cumulative volume of inflow, estimated and measured cumulative volumes of outflow, and cumulative volume of water stored in Edmore Coulee subbasin, Starkweather Coulee subbasin, Calio Coulee subbasin, and Mauvais Coulee subbasin for the chain of lakes during April through October 1993

[Numbers were rounded after computations; numbers in parentheses are negative; --, no data]

Month	Cumulative volume of rainfall (acre-feet)	Cumulative volume of inflow (acre-feet)	Estimated cumulative volume of outflow (acre-feet)	Measured cumulative volume of outflow (acre-feet)	Cumulative volume of water stored (acre-feet)
April	46,100	15,200	8,840	2,700	6,350
May	331,000	16,900	4,240	4,100	12,600
June	1,040,000	19,000	(391)	6,340	19,300
July	1,910,000	60,900	2,240	19,000	58,700
August	2,240,000	169,000	86,900	109,000	82,300
September	2,320,000	185,000	142,000	168,000	43,600
October	--	188,000	164,000	194,000	24,400

One of the greatest runoffs in North Dakota for which records are available occurred in the Edmore Coulee subbasin during 1993. Gaged streamflows indicated that 3.25 inches of runoff flowed in Edmore Coulee and 12.2 inches of runoff flowed in Edmore Coulee Tributary during April through October (table 5). The gaged streamflows indicated that about 5.7 inches of runoff occurred in the entire Edmore Coulee subbasin during April through October. Runoff from Edmore Coulee Tributary during 1993 greatly exceeded runoff recorded during other floods in North Dakota. For example, during 1950, 6.67 inches of runoff flowed in the Forest River near Fordville, 7.66 inches of runoff flowed in the Tongue River at Akra, and 3.27 inches of runoff flowed in the Cannonball River at Breien; during 1966, 5.92 inches of runoff flowed in the West Branch Otter Creek near Beulah (see fig. 1 for locations within the State).

Table 5. Runoff in the Devils Lake Basin for April through October 1993 and in other basins for April through October during selected past floods in North Dakota

[--, no data]

Stream	Drainage area[1] (square miles)	Year	Volume of streamflow[2] (acre-feet)	Runoff for April through October[3] (inches)
Edmore Coulee	382 (282)	1993	56,300	3.25
Edmore Coulee Tributary	148 (104)	1993	79,100	12.2
Starkweather Coulee	310 (210)	1993	22,800	1.70
Mauvais Coulee	387 (377)	1993	25,100	1.24
Mauvais Coulee Tributary No. 3	60.2 (--)	1993	5,170	1.61
Little Coulee	350 (190)	1993	5,600	.42
Big Coulee	1,620 (1,460)	1993	59,800	.73
Channel A	930 (--)	1993	140,000	2.82
Forest River near Fordville	456 (336)	1950	138,000	6.67
Tongue River at Akra	160 (--)	1950	[4]65,300	7.66
Cannonball River at Breien	4,100 (--)	1950	715,000	3.27
Rush River at Amenia	116 (--)	1979	24,600	3.97
West Branch Otter Creek near Beulah	26.5 (--)	1966	8,370	5.92
Cart Creek at Mountain	16.9 (--)	1964	2,730	3.03
Little Missouri River at Marmarth	4,640 (--)	1944	707,000	2.86

[1]First line represents total drainage area; second line, in parentheses, represents contributing drainage area.

[2]Numbers have been rounded.

[3]If the contributing drainage area was available, runoff from the total drainage area and runoff from the contributing drainage area were averaged.

[4]Volume of streamflow for April through June.

Downstream of the Chain of Lakes

Discharge from the chain of lakes flows to Devils Lake via Big Coulee (includes streamflow from Little Coulee) and Channel A. Big Coulee begins at the outlet of Lake Irvine, and Channel A begins at the outlet of Dry Lake (fig. 1). Little Coulee flows into Big Coulee downstream of the chain of lakes before entering Devils Lake.

Runoff from spring snowmelt caused an increase in streamflow in Big Coulee during 6 weeks in April and May (fig. 6). Maximum daily streamflow during the snowmelt period was 55 cubic feet per second on April 20. Summer precipitation also caused an increase in streamflow in Big Coulee. Streamflow increased from a minimum of 5.70 cubic feet per second on June 27 to a maximum of 346 cubic feet per second on September 13 and then gradually decreased to 204 cubic feet per second on October 31.

Runoff from spring snowmelt caused an increase in streamflow in Channel A during the first 2 weeks in April (fig. 6). Maximum daily streamflow during the snowmelt period was 75 cubic feet per second on April 13. Between mid-April and mid-June, streamflow generally was less than 1 cubic foot per second. Streamflow began to increase in mid-June, reached a maximum daily value of 1,540 cubic feet per second on August 15 and 16, and then decreased to 95 cubic feet per second on October 31. A peak of record of 1,560 cubic feet per second occurred on August 15 and was within 2.5 percent of the 1,600-cubic-foot-per second peak measured in 1979 by the North Dakota State Water Commission (1980).

Between April and mid-July, flow in Little Coulee averaged about 0.04 cubic foot per second. Streamflow began to increase in mid-July, reached a maximum of 181 cubic feet per second on July 29, and then decreased to 2.0 cubic feet per second on October 31.

Devils Lake and East Devils Lake

A water budget was calculated for Devils Lake and East Devils Lake. The budget includes direct precipitation and streamflow from Big Coulee (includes streamflow from Little Coulee) and Channel A (figs. 6 and 7) but does not include additional sources of surface-water inflow or loss of water to evaporation. The change in the volume of water stored (fig. 7) was calculated from data taken from elevation-capacity tables. The water budget can be separated into three periods--pre-flood conditions (April and May), increased summer precipitation (June and July), and increased streamflow (August through October). Between April 1 and May 26, the volume of water stored in Devils Lake and East Devils Lake increased 10,100 acre-feet; direct precipitation was 10,200 acre-feet and streamflow was 4,080 acre-feet. Between May 27 and August 4, the volume of water stored in Devils Lake and East Devils Lake increased 82,400 acre-feet; direct precipitation was 67,600 acre-feet and streamflow was 22,500 acre-feet. Between August 5 and October 31, the volume of water stored in Devils Lake and East Devils Lake increased 140,000 acre-feet; direct precipitation was 12,000 acre-feet and streamflow was 173,000 acre-feet. The difference between the calculated change in the volume of water stored and the sum of direct precipitation and streamflow may be attributed largely to evaporation.

SURFACE-WATER QUALITY IN THE DEVILS LAKE BASIN DURING 1993

Upstream of the Chain of Lakes

During April through October, 11 water-quality samples were collected from Edmore Coulee, 3 were collected from Edmore Coulee Tributary, 9 were collected from Starkweather Coulee, 9 were collected from Mauvais Coulee, and 3 were collected from Mauvais Coulee Tributary No. 3 (fig. 1; table 6).

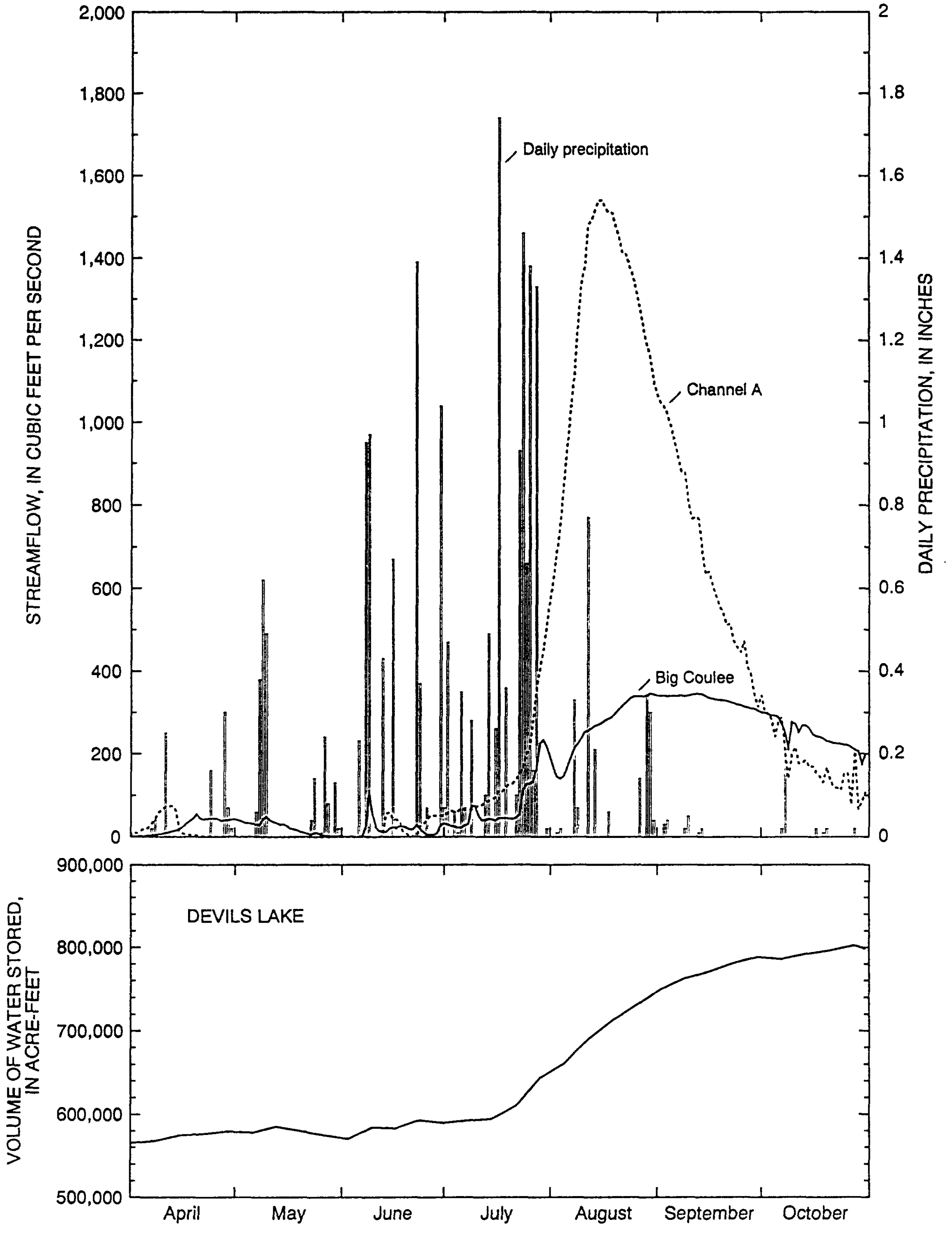

Figure 6. Streamflow in Big Coulee and Channel A, daily precipitation at the city of Devils Lake, and volume of water stored in Devils Lake, April through October 1993.

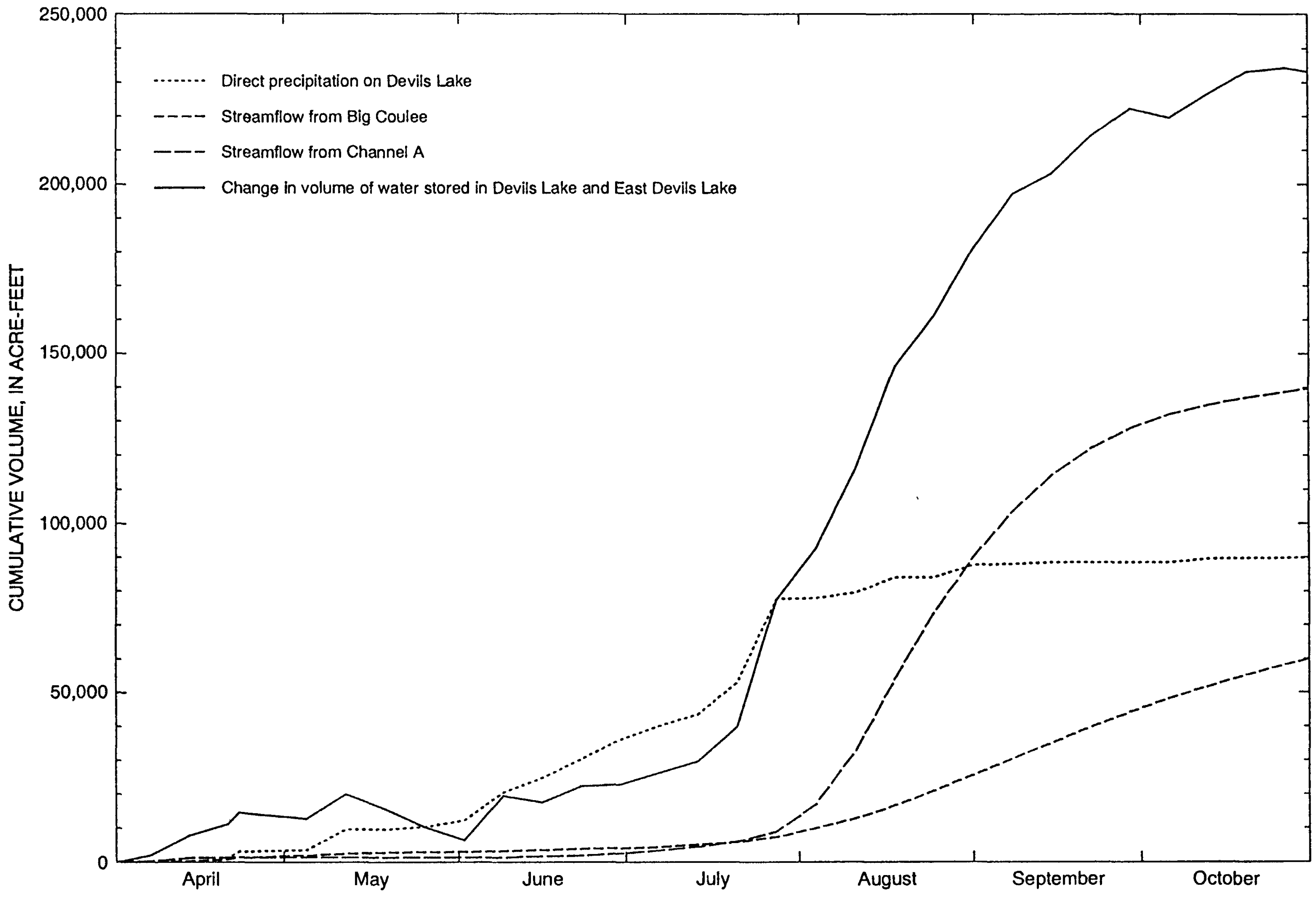

Figure 7. Cumulative volumes of direct precipitation on Devils Lake, streamflow from Big Coulee and Channel A, and changes in the volume of water stored in Devils Lake and East Devils Lake, April through October 1993.

Table 6. Dissolved-solids and selected nutrient concentrations for Edmore Coulee, Edmore Coulee Tributary, Starkweather Coulee, Mauvais Coulee, and Mauvais Coulee Tributary No. 3 during April through October 1993

[mg/L, milligrams per liter; <, less than indicated detection level; --, no data]

Sampling date	Dissolved solids (mg/L)	Nitrite plus nitrate, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Ammonia plus organic nitrogen, total (mg/L as N)	Phosphorus, total (mg/L as P)	Ortho-phosphate, dissolved (mg/L as P)
			Edmore Coulee			
04-06-93	240	3.3	0.15	1.4	0.56	0.50
04-07-93	239	3.2	.13	1.3	.55	.50
04-13-93	370	1.5	.03	1.5	.43	.37
04-21-93	428	<.05	.10	1.3	.23	.15
05-13-93	492	<.05	.03	1.3	.19	.43
08-02-93	--	<.05	.04	.80	.33	.25
08-17-93	407	<.05	.07	1.0	.40	.38
08-31-93	494	.09	.08	1.2	.44	.40
09-08-93	584	<.05	.05	1.2	.38	.34
09-21-93	627	<.05	.05	1.4	.29	.26
10-04-93	778	<.05	.03	1.5	.16	.12
			Edmore Coulee Tributary			
08-19-93	382	<0.05	0.03	1.1	0.27	0.20
09-14-93	538	--	--	--	--	--
10-04-93	634	<.05	.03	1.7	.34	.29
			Starkweather Coulee			
04-01-93	264	3.6	0.05	2.0	0.64	0.58
04-05-93	263	3.6	.07	1.4	.39	.32
04-15-93	348	1.2	.03	1.0	.29	.28
05-13-93	551	<.05	.03	1.3	.50	.14
08-03-93	368	<.05	.04	.80	.28	.20
08-17-93	497	<.05	.05	<.20	.24	.21
08-30-93	506	<.05	.02	1.2	.24	.20
09-21-93	559	<.05	.04	1.3	.12	.10
10-05-93	622	<.05	.03	1.5	.09	.07
			Mauvais Coulee			
04-05-93	1,380	0.09	0.83	2.1	0.61	0.40
04-15-93	387	.13	.02	1.1	.31	.26
04-22-93	500	<.05	.05	1.0	.24	.20
05-12-93	713	<.05	.03	1.3	.30	.24
08-03-93	695	<.05	.03	1.4	.38	.29
08-17-93	652	<.05	.04	<.20	.50	.45
08-30-93	761	<.05	.05	1.4	.51	.49
09-23-93	740	<.05	.03	1.4	.44	.43
10-06-93	792	<.05	.02	1.5	.34	.30
			Mauvais Coulee Tributary No. 3			
04-06-93	492	--	--	--	--	--
04-22-93	469	--	--	--	--	--
09-15-93	613	--	--	--	--	--

Dissolved-solids concentrations in samples collected from Edmore Coulee ranged from 239 mg/L on April 7 to 778 mg/L on October 4. Dissolved nitrite plus nitrate concentrations ranged from less than 0.05 mg/L in 7 of the 11 samples to 3.3 mg/L on April 6. Dissolved ammonia concentrations ranged from 0.03 mg/L on April 13, May 13, and October 4 to 0.15 mg/L on April 6. Total ammonia plus organic nitrogen concentrations ranged from 0.80 mg/L on August 2 to 1.5 mg/L on April 13 and October 4. Total phosphorus concentrations ranged from 0.16 mg/L on October 4 to 0.56 mg/L on April 6. Dissolved orthophosphate concentrations ranged from 0.12 mg/L on October 4 to 0.50 mg/L on April 6 and 7.

Dissolved-solids concentrations in samples collected from Starkweather Coulee ranged from 263 mg/L on April 5 to 622 mg/L on October 5. Dissolved nitrite plus nitrate concentrations ranged from less than 0.05 mg/L in six of the nine samples to 3.6 mg/L on April 1 and 5. Dissolved ammonia concentrations ranged from 0.02 mg/L on August 30 to 0.07 mg/L on April 5. Total ammonia plus organic nitrogen concentrations ranged from less than 0.20 mg/L on August 17 to 2.0 mg/L on April 1. Total phosphorus concentrations ranged from 0.09 mg/L on October 5 to 0.64 mg/L on April 1. Dissolved orthophosphate concentrations ranged from 0.07 mg/L on October 5 to 0.58 mg/L on April 1.

Dissolved-solids concentrations in samples collected from Mauvais Coulee ranged from 387 mg/L on April 15 to 1,380 mg/L on April 5. Dissolved nitrite plus nitrate concentrations ranged from less than 0.05 mg/L in seven of the nine samples to 0.13 mg/L on April 15. Dissolved ammonia concentrations ranged from 0.02 mg/L on April 15 and October 6 to 0.83 mg/L on April 5. Total ammonia plus organic nitrogen concentrations ranged from less than 0.20 mg/L on August 17 to 2.1 mg/L on April 5. Total phosphorus concentrations ranged from 0.24 mg/L on April 22 to 0.61 mg/L on April 5. Dissolved orthophosphate concentrations ranged from 0.20 mg/L on April 22 to 0.49 mg/L on August 30.

Generally, dissolved-solids concentrations for coulees that flow into the chain of lakes were at a minimum during the spring and a maximum during the late summer and fall. Nutrient concentrations were at a maximum during the spring and a minimum during the late summer and fall except in Mauvais Coulee where total phosphorus concentrations and dissolved orthophosphate concentrations were at a minimum during the spring and at or near a maximum during the spring and late summer.

Cumulative dissolved-solids, total ammonia plus organic nitrogen, and total phosphorus loads for coulees that flow into the chain of lakes (fig. 8) were at a minimum during spring snowmelt and low-flow conditions before flooding and a maximum during the late summer. Dissolved nitrite plus nitrate loads for Edmore Coulee and Starkweather Coulee were at a maximum during spring snowmelt.

During April through October, cumulative dissolved-solids loads were greatest in Edmore Coulee Tributary and least in Mauvais Coulee Tributary No. 3 (table 7). Dissolved nitrite plus nitrate loads were greatest in Edmore Coulee and least in Mauvais Coulee. Dissolved ammonia, total phosphorus, and dissolved orthophosphate loads were greatest in Edmore Coulee and least in Starkweather Coulee. Total ammonia plus organic nitrogen loads were greatest in Edmore Coulee Tributary and least in Starkweather Coulee. About 37 percent of the dissolved-solids load and about 43 percent of the total ammonia plus organic nitrogen load was attributed to Edmore Coulee Tributary. Between about 36 and 43 percent of each of the remaining nutrient loads was attributed to Edmore Coulee.

Chain of Lakes

During May through October, four water-quality samples were collected from Sweetwater Lake, Morrison Lake, Dry Lake, and Lake Irvine and three water-quality samples were collected from Lake Alice (fig. 1; table 8). Except for Lake Alice, the first sampling was conducted on May 12 after ice on the lakes melted. The next sampling was conducted on August 10 after most of the summer precipitation had

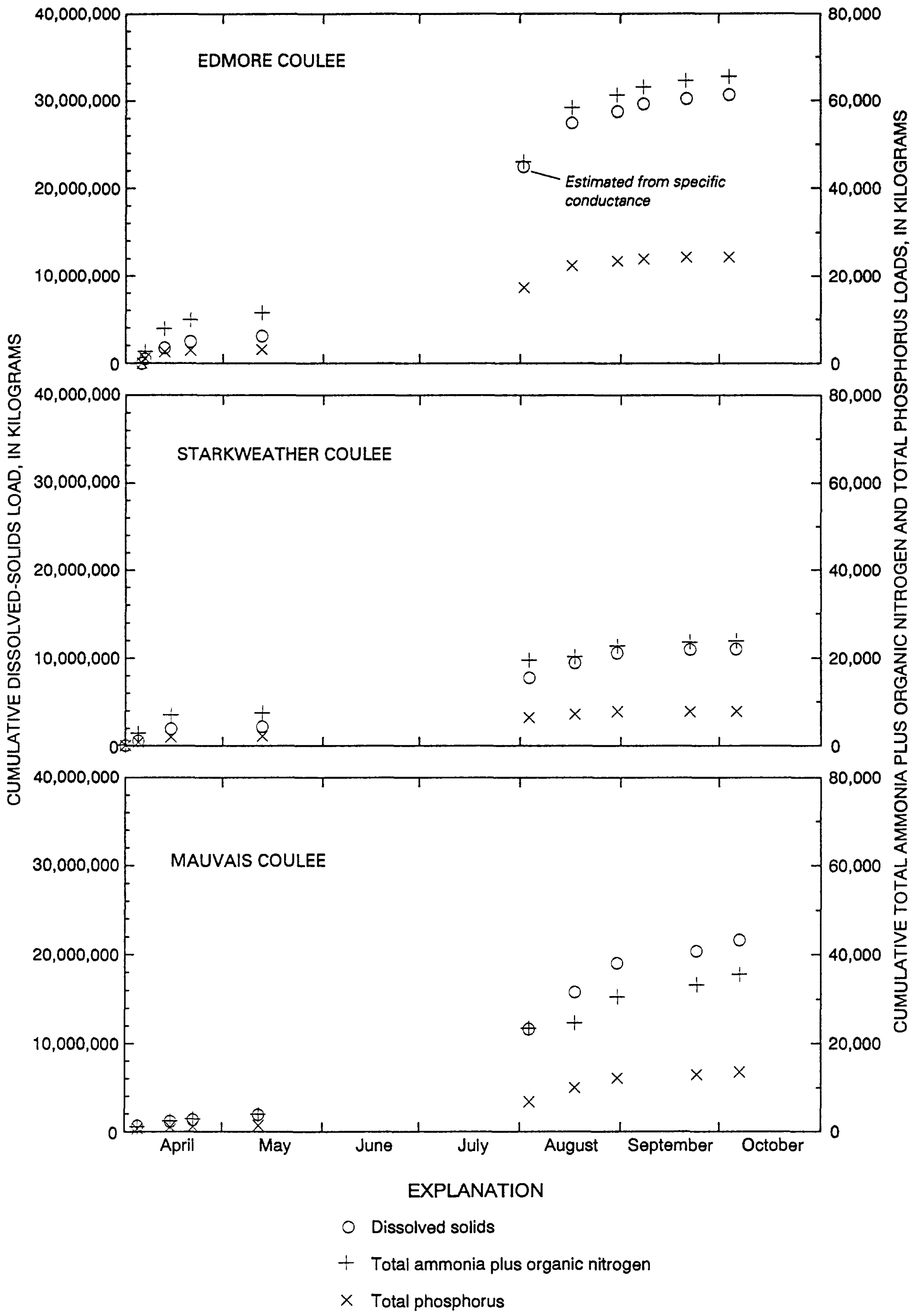

Figure 8. Cumulative dissolved-solids, total ammonia plus organic nitrogen, and total phosphorus loads for Edmore Coulee, Starkweather Coulee, and Mauvais Coulee, April through October 1993.

occurred and shortly after streamflow in tributaries to the lakes had peaked. The remaining two samplings were conducted on September 14 and 15 and October 20 and 21 well after streamflow in tributaries to the lakes had peaked.

Table 7. Cumulative dissolved-solids and selected nutrient loads for Edmore Coulee, Edmore Coulee Tributary, Starkweather Coulee, Mauvais Coulee, and Mauvais Coulee Tributary No. 3 during April through October 1993

[Numbers have been rounded after computations; kg, kilograms; --, no data]

Sampling location	Dissolved solids (kg)	Nitrite plus nitrate, dissolved (kg as N)	Ammonia, dissolved (kg as N)	Ammonia plus organic nitrogen, total (kg as N)	Phosphorus, total (kg as P)	Ortho-phosphate, dissolved (kg as P)
Edmore Coulee	30,700,000	15,100	3,500	65,500	24,400	20,400
Edmore Coulee Tributary	39,600,000	4,260	2,560	95,500	23,200	17,300
Starkweather Coulee	11,000,000	13,800	1,130	23,800	7,870	6,140
Mauvais Coulee	21,500,000	1,650	1,320	35,300	13,000	11,100
Mauvais Coulee Tributary No. 3	3,830,000	--	--	--	--	--
Total	107,000,000	34,800	8,510	220,000	68,500	54,900

Dilution by direct precipitation on Sweetwater Lake, Morrison Lake, and Dry Lake during July generally resulted in decreased dissolved-solids concentrations. Dissolved-solids concentration data for the streams and lakes (tables 6 and 8) indicate that streamflow does not contribuate to the dissolved-solids concentration decrease in the lakes. Decreases in dissolved-solids concentrations from May to early August ranged from about 39 percent in water samples collected from Sweetwater Lake to about 5 percent in water samples collected from Dry Lake (table 8). However, during the same period, dissolved-solids concentrations increased about 3 percent in Lake Irvine. Dissolved-solids concentrations in Sweetwater Lake and Morrison Lake decreased between May and August and then increased in September and October. Dissolved-solids concentrations in Dry Lake decreased from May through September and then increased in October. Dissolved-solids concentrations in Lake Alice decreased from August to September and then increased in October. In contrast, dissolved-solids concentrations in Lake Irvine increased steadily from May to September and then remained constant through October. By October 20, dissolved-solids concentrations in Lake Alice and Lake Irvine were about equal. The increases in dissolved-solids concentrations in the chain of lakes probably were caused by upstream flow moving through the system, by evaporation, or by inundation of saline soils at the margin of the lakes.

The maximum dissolved nitrite plus nitrate concentrations for the chain of lakes occurred in May in Sweetwater Lake (0.26 mg/L) and Lake Irvine (0.21 mg/L) and in October in Lake Alice (0.17 mg/L) (table 8). All remaining dissolved nitrite plus nitrate concentrations were less than 0.05 mg/L. The maximum dissolved ammonia concentrations occurred in September in Sweetwater Lake, Lake Alice, and Lake Irvine and in May and September in Morrison Lake and Dry Lake. The maximum concentrations ranged from 0.03 mg/L in Dry Lake to 0.10 mg/L in Lake Alice. Total ammonia plus organic nitrogen concentrations did not vary by more than 0.8 mg/L between the sampling periods except in Dry Lake where the concentration increased from 0.9 mg/L on September 15 to 2.3 mg/L on October 20. Variations in total phosphorus and dissolved orthophosphate concentrations were not systematic between the lakes during May through October.

Table 8. Dissolved-solids and selected nutrient concentrations for Sweetwater Lake, Morrison Lake, Dry Lake, Lake Alice, and Lake Irvine during May through October 1993

[mg/L, milligrams per liter; <, less than indicated detection level; --, no data]

Sampling date	Dissolved solids (mg/L)	Nitrite plus nitrate, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Ammonia plus organic nitrogen, total (mg/L as N)	Phosphorus, total (mg/L as P)	Ortho-phosphate, dissolved (mg/L as P)
			Sweetwater Lake			
05-12-93	545	0.26	0.03	1.5	0.15	0.08
08-10-93	335	--	--	--	--	--
09-14-93	504	<.05	.05	1.2	.29	.27
10-21-93	579	<.05	<.01	1.4	.23	.14
			Morrison Lake			
05-12-93	610	<0.05	0.09	1.8	0.12	0.06
08-10-93	363	--	--	--	--	--
09-14-93	440	<.05	.09	1.2	.31	.26
10-21-93	495	<.05	<.01	1.5	.15	.05
			Dry Lake			
05-12-93	526	<0.05	0.03	1.2	0.30	0.19
08-10-93	499	--	--	--	--	--
09-15-93	417	<.05	.03	.90	.27	.17
10-20-93	478	<.05	<.01	2.3	.87	.04
			Lake Alice			
08-10-93	631	--	--	--	--	--
09-15-93	525	<0.05	0.10	1.2	0.47	0.44
10-20-93	597	.17	.07	1.6	.60	.35
			Lake Irvine			
05-12-93	535	0.21	0.02	0.90	0.35	0.30
08-10-93	551	--	--	--	--	--
09-15-93	592	<.05	.05	1.7	.53	.44
10-20-93	592	<.05	.03	1.3	.31	.27

Chemical mass balances were calculated for Sweetwater Lake, Morrison Lake, Dry Lake, Lake Alice, and Lake Irvine for each of the sampling periods (table 9). Dissolved-solids masses for Sweetwater Lake, Morrison Lake, and Dry Lake were at a maximum in August and then declined through October. Dissolved-solids for Lake Alice and Lake Irvine were at a maximum in September and then declined by October. Most of the nitrogen in the chain of lakes during May through October was in the form of total ammonia plus organic nitrogen. The total ammonia plus organic nitrogen mass was greatest in Dry Lake in October and least in Lake Irvine in May. In general, total phosphorus and dissolved orthophosphate masses were greatest in September. During September, the dissolved orthophosphate mass comprised between 83 and 94 percent of the total phosphorus mass in the various lakes. An exception was Dry Lake, where total phosphorus mass was greatest in October.

Downstream of the Chain of Lakes

During April through October, 12 water-quality samples were collected from Big Coulee, 14 were collected from Channel A, and 1 was collected from Little Coulee (fig. 1; table 10). Dissolved-solids concentrations in samples collected from Big Coulee ranged from 372 mg/L on April 14 to 647 mg/L on October 26. Dissolved nitrite plus nitrate concentrations ranged from less than 0.05 mg/L in 5 of the 12 samples to 1.8 mg/L on April 2. Dissolved ammonia concentrations ranged from 0.01 mg/L on April 14 to 0.38 mg/L on April 2. Total ammonia plus organic nitrogen concentrations ranged from less than 0.20 mg/L on August 16 to 2.0 mg/L on April 2. Total phosphorus concentrations ranged from 0.26 mg/L on April 14 to 0.61 mg/L on August 25. Dissolved orthophosphate concentrations ranged from 0.15 mg/L on April 14 to 0.55 mg/L on August 16.

Table 9. Dissolved-solids and selected nutrient masses for Sweetwater Lake, Morrison Lake, Dry Lake, Lake Alice, and Lake Irvine during May through October 1993

[kg, kilograms; --, no data]

Sampling date	Dissolved solids (kg)	Nitrite plus nitrate, dissolved (kg as N)	Ammonia, dissolved (kg as N)	Ammonia plus organic nitrogen, total (kg as N)	Phosphorus, total (kg as P)	Ortho-phosphate, dissolved (kg as P)
			Sweetwater Lake			
05-12-93	8,000,000	3,800	439	21,900	2,190	1,170
08-10-93	14,800,000	--	--	--	--	--
09-14-93	1,550,000	1,460	1,460	35,100	8,490	7,900
10-21-93	1,520,000	1,220	245	34,300	5,630	3,430
			Morrison Lake			
05-12-93	4,460,000	366	658	13,200	878	439
08-10-93	8,010,000	--	--	--	--	--
09-14-93	6,440,000	732	1,320	17,600	4,540	3,800
10-21-93	6,060,000	612	122	18,400	1,840	612
			Dry Lake			
05-12-93	13,300,000	1,270	760	30,400	7,600	4,810
08-10-93	28,900,000	--	--	--	--	--
09-15-93	14,800,000	1,770	1,060	31,900	9,570	6,025
10-20-93	10,300,000	1,080	216	49,600	18,800	863
			Lake Alice			
08-10-93	13,100,000	--	--	--	--	--
09-15-93	13,600,000	1,290	2,580	31,000	12,100	11,400
10-20-93	9,940,000	2,830	1,160	26,600	9,990	5,830
			Lake Irvine			
05-12-93	5,500,000	2,160	206	9,260	3,600	3,090
08-10-93	11,400,000	--	--	--	--	--
09-15-93	15,300,000	1,290	1,290	43,900	13,700	11,400
10-20-93	9,860,000	832	499	21,600	5,160	4,490

Dissolved-solids concentrations in samples collected from Channel A ranged from 344 mg/L on April 2 to 1,030 mg/L on April 14. Dissolved nitrite plus nitrate concentrations ranged from less than 0.05 mg/L in 9 of the 14 samples to 2.9 mg/L on April 2. Dissolved ammonia concentrations ranged from 0.02 mg/L on April 14 and October 7 to 0.13 mg/L on August 26. Total ammonia plus organic nitrogen concentrations ranged from less than 0.20 mg/L on August 16 to 1.9 mg/L on April 14. Total phosphorus concentrations ranged from 0.06 mg/L on May 12 to 0.55 mg/L on April 14. Dissolved orthophosphorus concentrations ranged from 0.01 mg/L on May 12 to 0.46 mg/L on April 14.

Table 10. Dissolved-solids and selected nutrient concentrations for Big Coulee, Channel A, and Little Coulee during April through October 1993

[mg/L, milligrams per liter; <, less than indicated detection level; --, no data]

Sampling date	Dissolved solids (mg/L)	Nitrite plus nitrate, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Ammonia plus organic nitrogen, total (mg/L as N)	Phosphorus, total (mg/L as P)	Ortho-phosphate, dissolved (mg/L as P)
			Big Coulee			
04-02-93	484	1.8	0.38	2.0	0.50	0.44
04-14-93	372	<.05	.01	1.2	.26	.15
04-23-93	566	<.05	.02	1.1	.33	.29
05-11-93	626	<.05	.03	1.0	.47	.44
07-08-93	622	.41	.06	1.1	.40	.38
08-16-93	589	<.05	.09	<.20	.58	.55
08-25-93	593	<.05	.10	1.4	.61	.52
09-03-93	612	.06	.10	1.2	.54	.54
09-13-93	602	.15	.20	1.5	.52	.50
09-22-93	611	.22	.11	1.3	.54	.52
10-06-93	614	.29	.05	1.3	.45	.43
10-26-93	647	.39	.09	1.2	.39	.39
			Channel A			
04-02-93	344	2.9	0.11	0.90	0.17	0.20
04-14-93	1,030	.06	.02	1.9	.55	.46
04-23-93	676	<.05	.04	1.1	.17	.12
05-12-93	570	<.05	.03	1.5	.06	.01
06-16-93	638	<.05	.04	1.0	.45	.42
07-08-93	576	.38	.04	.90	.45	.41
08-04-93	519	.16	.06	1.1	.42	.31
08-16-93	457	<.05	.05	<.20	.31	.27
08-26-93	403	.10	.13	1.3	.43	.34
09-02-93	399	<.05	.03	.80	.34	.30
09-13-93	420	<.05	.03	.80	.29	.19
09-22-93	429	<.05	.04	1.6	.32	.15
10-07-93	466	<.05	.02	1.6	.31	.06
10-25-93	491	<.05	.05	.80	.11	.05
			Little Coulee			
09-15-93	761	--	--	--	--	--

Cumulative dissolved-solids and nutrient loads for Channel A (fig. 9) were at a minimum during spring snowmelt and low-flow conditions before flooding and a maximum during the late summer or fall. By October, cumulative loads in Channel A were leveling off. Dissolved-solids and nutrient loads for Channel A were smaller than those for Big Coulee during spring snowmelt and low-flow conditions in June and July but larger during August, September, and October (fig. 9). Increases in cumulative dissolved-solids and nutrient loads for Big Coulee (fig. 9) were nearly linear from August to October. These sustained linear increases were in contrast to the reduced rate of increase in Channel A during September and October relative to during August (fig. 9).

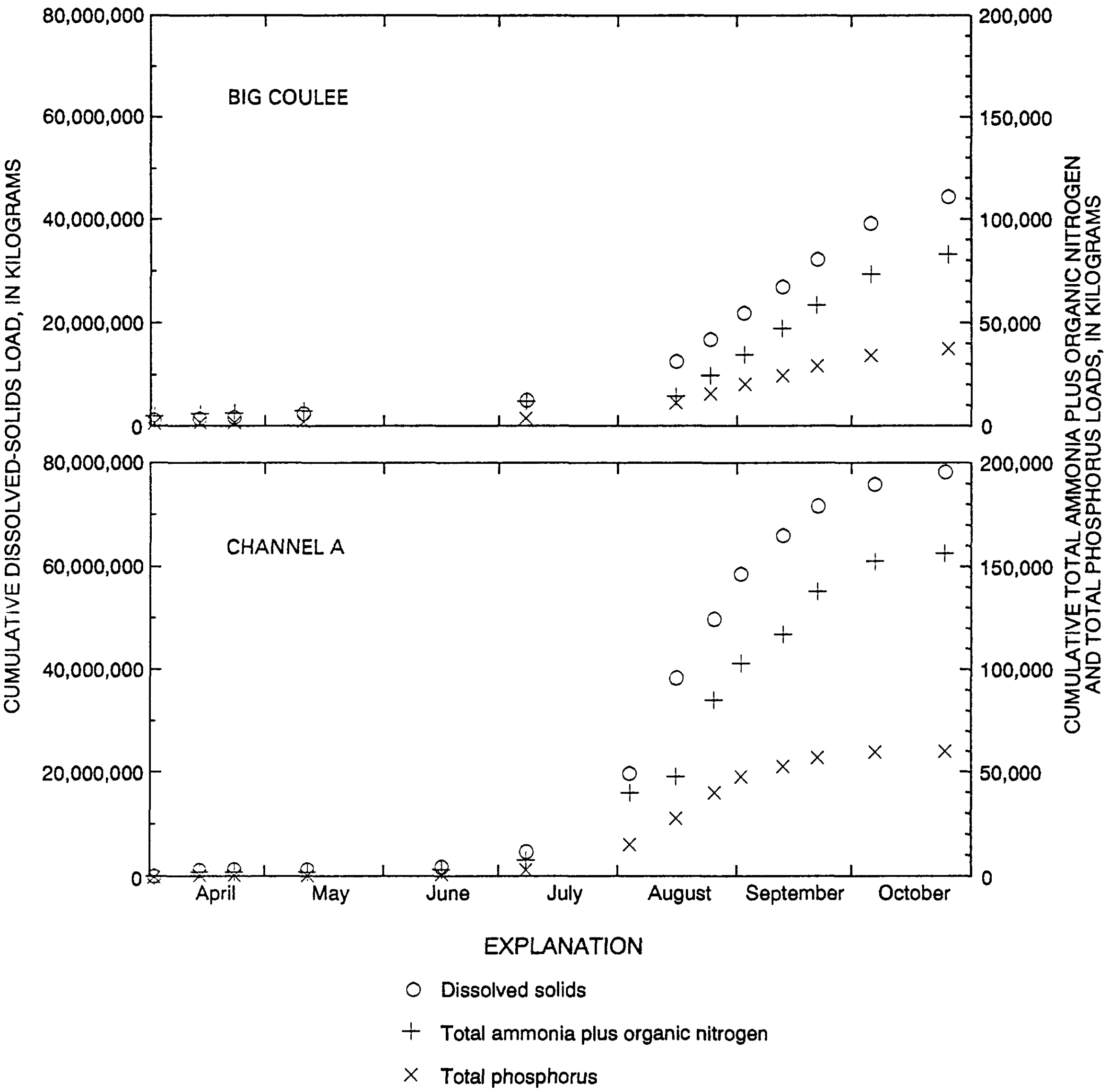

Figure 9. Cumulative dissolved-solids, total ammonia plus organic nitrogen, and total phosphorus loads for Big Coulee and Channel A, April through October 1993.

Nutrients in Channel A go directly into Devils Lake whereas nutrients in Big Coulee may not represent actual loading to Devils Lake because of possible biological and physical water-quality changes that might occur in Big Coulee. During April through October, cumulative dissolved-solids and nutrient loads for Channel A were greater than those for Big Coulee (table 11). About 64 percent of the dissolved-solids load was attributed to Channel A. Between about 48 and 65 percent of the remaining nutrient loads was attributed to Channel A.

Table 11. Cumulative dissolved-solids and selected nutrient loads for Big Coulee and Channel A during April through October 1993

[Numbers have been rounded; kg, kilograms]

Sampling location	Dissolved solids (kg)	Nitrite plus nitrate, dissolved (kg as N)	Ammonia, dissolved (kg as N)	Ammonia plus organic nitrogen, total (kg as N)	Phosphorus, total (kg as P)	Ortho-phosphate, dissolved (kg as P)
Big Coulee	44,500,000	17,400	7,870	83,000	37,400	35,400
Channel A	78,300,000	16,100	9,940	157,000	60,600	45,400
Total	123,000,000	33,500	17,800	240,000	98,000	80,800

Devils Lake and East Devils Lake

Decreases in dissolved-solids concentrations from May to early August ranged from about 77 percent in water samples collected from Sixmile Bay to about 9 percent in water samples collected from Main Bay, Creel Bay, and East Devils Lake (table 12). Decreases in the dissolved-solids concentrations in Devils Lake and East Devils Lake may have been the result of dilution by direct precipitation. However, during the same period, dissolved-solids concentrations increased about 6 percent in East Bay. Dissolved-solids concentrations in West Bay and Sixmile Bay decreased between May and August and then increased in September and October. The increases in dissolved-solids concentrations in September and October could be caused by mixing water between West Bay, Creel Bay, and Main Bay or by an increase in dissolved-solids mass in Devils Lake because of inundation of saline soils at the margin of the lake and not necessarily by flow from Channel A. Dissolved-solids concentrations in Main Bay and Creel Bay decreased from May through October. The initial decrease was the result of direct precipitation, and the decreases in September and October were the result of dilution by relatively fresh streamflow (fig. 7). Variations in dissolved-solids concentrations for East Bay and East Devils Lake were distinct from variations for the other bays. Dissolved-solids concentrations in East Bay increased from May to August and decreased in September and October. In contrast, dissolved-solids concentrations in East Devils Lake decreased from May to August, increased in September, and remained constant in October. However, the change in dissolved-solids concentrations in East Bay and East Devils Lake between May and October is very small.

The maximum dissolved nitrite plus nitrate concentration for West Bay occurred in October. Concentrations were less than 0.05 mg/L during May, August, and September (table 12). In contrast, the maximum dissolved nitrite plus nitrate concentrations for the other four bays and East Devils Lake occurred in either May or August. Concentrations generally were less than 0.05 mg/L at other times. Variations in dissolved ammonia, total ammonia plus organic nitrogen, total phosphorus, and dissolved orthophosphate concentrations were not systematic for any of the bays or for East Devils Lake during May through October.

Table 12. Dissolved-solids and selected nutrient concentrations for Devils Lake and East Devils Lake during May through October 1993

[mg/L, milligrams per liter; <, less than indicated detection level]

Sampling date	Dissolved solids (mg/L)	Nitrite plus nitrate, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Ammonia plus organic nitrogen, total (mg/L as N)	Phosphorus, total (mg/L as P)	Ortho-phosphate, dissolved (mg/L as P)
			Devils Lake, West Bay			
05-11-93	2,320	<0.05	0.05	2.2	0.11	<0.01
08-09-93	1,350	<.05	.03	1.6	.13	.04
09-14-93	1,510	<.05	.11	2.4	.16	.06
10-21-93	1,600	.39	.47	2.5	.21	.11
			Devils Lake, Sixmile Bay			
05-11-93	3,680	<0.05	0.11	2.7	0.09	0.03
08-09-93	832	.29	.04	1.3	.35	.28
09-14-93	1,110	<.05	.03	1.4	.26	.17
10-21-93	2,120	<.05	.02	1.8	.13	.07
			Devils Lake, Main Bay			
05-11-93	4,230	0.17	0.14	2.8	0.13	0.06
08-09-93	3,840	<.05	.03	3.4	.23	.11
09-14-93	3,270	.15	.20	2.4	.24	.19
10-21-93	3,100	<.05	<.01	2.2	.14	.04
			Devils Lake, Creel Bay			
05-11-93	4,280	0.22	0.28	3.0	0.15	0.09
08-09-93	3,890	<.05	.04	4.4	.32	.17
09-14-93	3,350	.16	.37	3.1	.26	.19
10-21-93	3,210	<.05	.05	2.5	.14	.05
			Devils Lake, East Bay			
05-11-93	5,890	0.16	0.02	2.6	0.18	0.11
08-09-93	6,250	<.05	.08	6.3	.41	.11
09-14-93	5,970	<.05	.16	3.9	.26	.16
10-21-93	5,780	.14	.42	4.5	.32	.20
			East Devils Lake			
05-11-93	10,400	<0.05	0.03	3.4	0.15	0.06
08-10-93	9,480	.10	.07	4.4	.26	.17
09-14-93	10,100	<.05	.05	3.8	.21	.11
10-21-93	10,100	<.05	.11	3.2	.15	.10

Chemical mass balances were calculated for the five bays and for East Devils Lake for each of the sampling periods. Precipitation in June and July resulted in a decrease in the dissolved-solids masses for West Bay and Sixmile Bay. The combined dissolved-solids mass for West Bay and Sixmile Bay decreased from 175 million kilograms in May to 100 million kilograms in August. The substantial decrease may have resulted from displacement of relatively saline lake water in West Bay and Sixmile Bay by precipitation and relatively fresh surface-water inflow. For both bays, the dissolved-solids masses increased in September and October. The combined dissolved-solids mass for Main Bay and Creel Bay decreased from 1.8 billion kilograms in May and August to 1.5 billion kilograms in October. The combined dissolved-solids mass for West Bay, Sixmile Bay, Main Bay, and Creel Bay decreased from May to August and remained constant from August through October (table 13).

Table 13. Dissolved-solids and selected nutrient masses for Devils Lake and East Devils Lake during May through October 1993

[kg, kilograms]

Sampling date	Dissolved solids (kg)	Nitrite plus nitrate, dissolved (kg as N)	Ammonia, dissolved (kg as N)	Ammonia plus organic nitrogen, total (kg as N)	Phosphorus, total (kg as P)	Ortho-phosphate, dissolved (kg as P)
			West end of Devils Lake (West Bay, Sixmile Bay, Main Bay, and Creel Bay)			
05-11-93	1,900,000,000	73,000	64,000	1,300,000	60,000	26,000
08-10-93	1,800,000,000	33,000	17,000	1,700,000	120,000	61,000
09-14-93	1,800,000,000	81,000	115,000	1,500,000	140,000	110,000
10-21-93	1,800,000,000	65,000	52,000	1,400,000	97,000	34,000
			East end of Devils Lake (East Bay and East Devils Lake)			
05-11-93	2,300,000,000	36,000	7,100	870,000	50,000	27,000
08-10-93	2,600,000,000	23,000	26,000	1,900,000	120,000	45,000
09-14-93	2,800,000,000	19,000	47,000	1,500,000	93,000	55,000
10-21-93	2,900,000,000	44,000	125,000	1,600,000	100,000	66,000
			Total (Devils Lake and East Devils Lake)			
05-11-93	4,200,000,000	109,000	71,100	2,170,000	110,000	53,000
08-10-93	4,400,000,000	56,000	43,000	3,600,000	240,000	106,000
09-14-93	4,600,000,000	100,000	162,000	3,000,000	233,000	165,000
10-21-93	4,700,000,000	109,000	177,000	3,000,000	197,000	100,000

The dissolved-solids mass for East Bay increased from about 1.1 billion kilograms in May to about 1.5 billion kilograms in October. The dissolved-solids mass for East Devils Lake decreased from about 1.2 billion kilograms in May to about 1.1 billion kilograms in August and then increased to about 1.3 billion kilograms in October. The combined dissolved-solids mass for East Bay and East Devils Lake increased from about 2.3 billion kilograms in May to about 2.9 billion kilograms in October (table 13). Because neither East Bay nor East Devils Lake receives substantial stream inflow, the increase in dissolved-solids mass between May and October probably was the result of west to east transport of dissolved solids in Devils Lake.

Between May and October, the dissolved-solids mass for Devils Lake and East Devils Lake increased 500 million kilograms (table 13). Only about 25 percent (123 million kilograms; table 11) of the increase can be attributed to streamflow. Either the water-quality sampling was inadequate to define water-quality variability in the Devils Lake Basin or other sources of dissolved solids were more important than tributary inflow. Komor (1992, 1994) and Lent (1994) indicated the importance of bottom-sediment sources to the chemical budget of Devils Lake. The dissolution of saline minerals during flooding of the lakeshore also could be an important source of dissolved solids to the lake.

Systematic variations in nutrient masses for individual bays are difficult to identify. However, broad observations can be made from combined data for West Bay, Sixmile Bay, Main Bay, and Creel Bay, for

East Bay and East Devils Lake, and for the entire lake including East Devils Lake (table 13). Most of the nitrogen in Devils Lake during May through October was in the form of total ammonia plus organic nitrogen. The total ammonia plus organic nitrogen mass for the entire lake was at a minimum in May and a maximum in August. The total ammonia plus organic nitrogen mass for the entire lake increased about 38 percent between May and October.

The dissolved orthophosphate mass for Devils Lake and East Devils Lake comprised between about 44 and 71 percent of the total phosphorus mass. The total phosphorus mass for Devils Lake and East Devils Lake was at a minimum in May, increased to a maximum in August, and decreased in September and October. The total phosphorus mass for Devils Lake and East Devils Lake increased about 79 percent between May and October.

SUMMARY

Greater-than-normal precipitation during the summer of 1993 caused severe flooding in a nine-state area, including North Dakota. Large areas in the Devils Lake Basin were flooded as a result of the precipitation, and water from these areas drained slowly through the chain of lakes into Devils Lake. Devils Lake rose from 1,423.0 feet above sea level on June 10 to 1,427.0 feet above sea level on September 28, largely in response to direct precipitation on the lake. This report summarizes the results of surface-water quantity and quality monitoring designed to document the effects of flooding in the Devils Lake Basin. Specific objectives are (1) to document the quantity and quality of streamflow in the Devils Lake Basin immediately before, during, and after the 1993 flood and (2) to document the hydrologic and chemical changes in the upstream chain of lakes and in Devils Lake during April through October 1993.

Precipitation at the city of Devils Lake during June through August was about 18.8 inches, about 10.7 inches greater than normal for the period. Precipitation was not distributed equally throughout the Devils Lake Basin. The Mauvais Coulee subbasin received about 17 inches of precipitation, and the Edmore Coulee subbasin received about 21.4 inches of precipitation, an average of about 2.63 inches more than the other subbasins. Total monthly average precipitation in the Devils Lake Basin for June through August was about 19.1 inches.

Several intense rainfalls during June and July caused an increase in streamflow in Edmore Coulee, Edmore Coulee Tributary, Starkweather Coulee, Mauvais Coulee, and Mauvais Coulee Tributary No. 3. Maximum daily streamflow was 1,170 cubic feet per second on July 31 in Edmore Coulee, 1,310 cubic feet per second on August 2 in Edmore Coulee Tributary, 332 cubic feet per second on July 30 and 31 in Starkweather Coulee, 696 cubic feet per second on August 2 in Mauvais Coulee, and 244 cubic feet per second on August 2 in Mauvais Coulee Tributary No. 3. A peak of record of 1,180 cubic feet per second occurred on Edmore Coulee on July 30, and a peak of record of 1,330 cubic feet per second occurred on Edmore Coulee Tributary on August 2. These peaks occurred as a result of the intense rainfalls.

During April through September, the cumulative volume of inflow to the chain of lakes was about 8 percent of the cumulative volume of rainfall and the measured cumulative volume of outflow from the chain of lakes was about 7 percent of the cumulative volume of rainfall. From April through October, the cumulative volume of water stored in the chain of lakes increased about 18,000 acre-feet. The cumulative volume of inflow to the chain of lakes was 188,000 acre-feet. The estimated cumulative volume of outflow from the chain of lakes was 164,000 acre-feet. The measured cumulative volume of outflow was 194,000 acre-feet. The cumulative volume of water stored in the chain of lakes increased from 6,350 acre-feet in April to 82,300 acre-feet in August and then decreased to 24,400 acre-feet in October.

Streamflow measured for Edmore Coulee Tributary indicated that 12.2 inches of runoff, one of the greatest runoffs in North Dakota for which records are available, occurred during April through October 1993. The runoff greatly exceeded that recorded during other floods in North Dakota. April-through-October runoff during selected past floods ranged from 2.86 inches in 1944 to 7.66 inches in 1950.

Streamflow reached a maximum of 346 cubic feet per second on September 13 in Big Coulee, 1,540 cubic feet per second on August 15 and 16 in Channel A, and 181 cubic feet per second on July 29 in Little Coulee. The maximum streamflow in Channel A occurred earlier than the maximum streamflow in Big Coulee, and the period of increased streamflow was notably shorter in Channel A than in Big Coulee. The peak of record in Channel A was within 2.5 percent of the peak measured in 1979 by the North Dakota State Water Commission.

Between April 1 and May 26, the volume of water stored in Devils Lake and East Devils Lake increased 10,100 acre-feet, mainly because of direct precipitation. Between May 27 and August 4, the volume of water stored in Devils Lake and East Devils Lake increased 82,400 acre-feet, also mainly because of direct precipitation. Between August 5 and October 31, the volume of water stored in Devils Lake and East Devils Lake increased 140,000 acre-feet, mainly because of streamflow.

During April through October, dissolved-solids concentrations in samples collected from Edmore Coulee ranged from 239 to 778 milligrams per liter. Dissolved-solids concentrations in samples collected from Starkweather Coulee ranged from 263 to 622 milligrams per liter. Dissolved-solids concentrations in samples collected from Mauvais Coulee ranged from 387 to 1,380 milligrams per liter. Nutrient concentrations for coulees that flow into the chain of lakes were at a maximum during the spring and a minimum during the late summer and fall except in Mauvais Coulee where total phosphorus concentrations and dissolved orthophosphate concentrations were at a minimum during the spring and at or near a maximum during the spring and late summer.

Cumulative dissolved-solids, total ammonia plus organic nitrogen, and total phosphorus loads for coulees that flow into the chain of lakes were at a minimum during spring snowmelt and low-flow conditions before flooding and a maximum during the late summer. Dissolved nitrite plus nitrate loads for Edmore Coulee and Starkweather Coulee were at a maximum during spring snowmelt. During April through October, cumulative dissolved-solids loads were greatest in Edmore Coulee Tributary and least in Mauvais Coulee Tributary No. 3. About 37 percent of the dissolved-solids load and about 43 percent of the total ammonia plus organic nitrogen load was attributed to Edmore Coulee Tributary. Between about 36 and 43 percent of each of the remaining nutrient loads was attributed to Edmore Coulee.

Dilution by direct precipitation on Sweetwater Lake, Morrison Lake, and Dry Lake during July generally resulted in decreased dissolved-solids concentrations. Dissolved-solids concentrations in water samples collected from the chain of lakes generally decreased from May to early August and generally increased in September and October. However, dissolved-solids concentrations in Lake Irvine increased from May to September and remained constant through October. Total ammonia plus organic nitrogen concentrations did not vary significantly during the sampling periods except in Dry Lake where the concentration increased from 0.9 milligram per liter on September 15 to 2.3 milligrams per liter on October 20. Variations in total phosphorus and dissolved orthophosphate concentrations were not systematic between the lakes during May through October.

Between May and August, the increase in dissolved-solids mass for Sweetwater Lake, Morrison Lake, and Dry Lake ranged from 3.55 million to 15.6 million kilograms. Between August and September, the dissolved-solids mass for Lake Alice increased 500,000 kilograms. Between May and September, the dissolved-solids mass for Lake Irvine increased 9.8 million kilograms. Increases in the total ammonia plus organic nitrogen mass for the chain of lakes ranged from about 39 to 133 percent between May and October. Increases in the total phosphorus mass for the chain of lakes ranged from about 43 to 157 percent between May and October.

During April through October, dissolved-solids concentrations in samples collected from Big Coulee ranged from 372 to 647 milligrams per liter. Dissolved-solids concentrations in samples collected from Channel A ranged from 344 to 1,030 milligrams per liter. Dissolved nitrite plus nitrate concentrations for Big Coulee and Channel A were small during low-flow conditions and increased during late summer, high-flow conditions. Generally, dissolved ammonia and total ammonia plus organic nitrogen concentrations for Big Coulee and Channel A were larger than corresponding concentrations of dissolved nitrite plus nitrate.

Cumulative dissolved-solids and nutrient loads for Channel A were at a minimum during spring snowmelt and low-flow conditions before flooding and a maximum during the late summer or fall. Dissolved-solids and nutrient loads for Channel A were smaller than those for Big Coulee during spring snowmelt and low-flow conditions in June and July. During April through October, cumulative dissolved-solids and nutrient loads for Channel A were greater than those for Big Coulee. About 64 percent of the dissolved-solids load was attributed to Channel A. Between about 48 and 65 percent of the remaining nutrient loads was attributed to Channel A.

Decreases in dissolved-solids concentrations from May to early August ranged from about 77 percent in Sixmile Bay to about 9 percent in Main Bay, Creel Bay, and East Devils Lake. Decreases in the dissolved-solids concentrations in Devils Lake and East Devils Lake may have been the result of dilution by direct precipitation. Dissolved-solids concentrations in West Bay and Sixmile Bay increased in September and October. The initial decrease in Main Bay and Creel Bay was the result of direct precipitation, and the decreases in September and October were the result of dilution by relatively fresh streamflow. Dissolved-solids concentrations in East Bay increased about 6 percent from May to August and decreased in September and October. Variations in dissolved ammonia, total ammonia plus organic nitrogen, total phosphorus, and dissolved orthophosphate concentrations were not systematic for any of the bays or for East Devils Lake.

Between May and October, the dissolved-solids mass for Devils Lake and East Devils Lake increased 500 million kilograms. Only about 25 percent of the increase can be attributed to streamflow. The dissolution of saline minerals during flooding of the lakeshore could be an important additional source of dissolved solids to the lake. The total ammonia plus organic nitrogen mass for Devils Lake and East Devils Lake increased about 38 percent between May and October. The total phosphorus mass for Devils Lake and East Devils Lake increased about 79 percent between May and October.

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