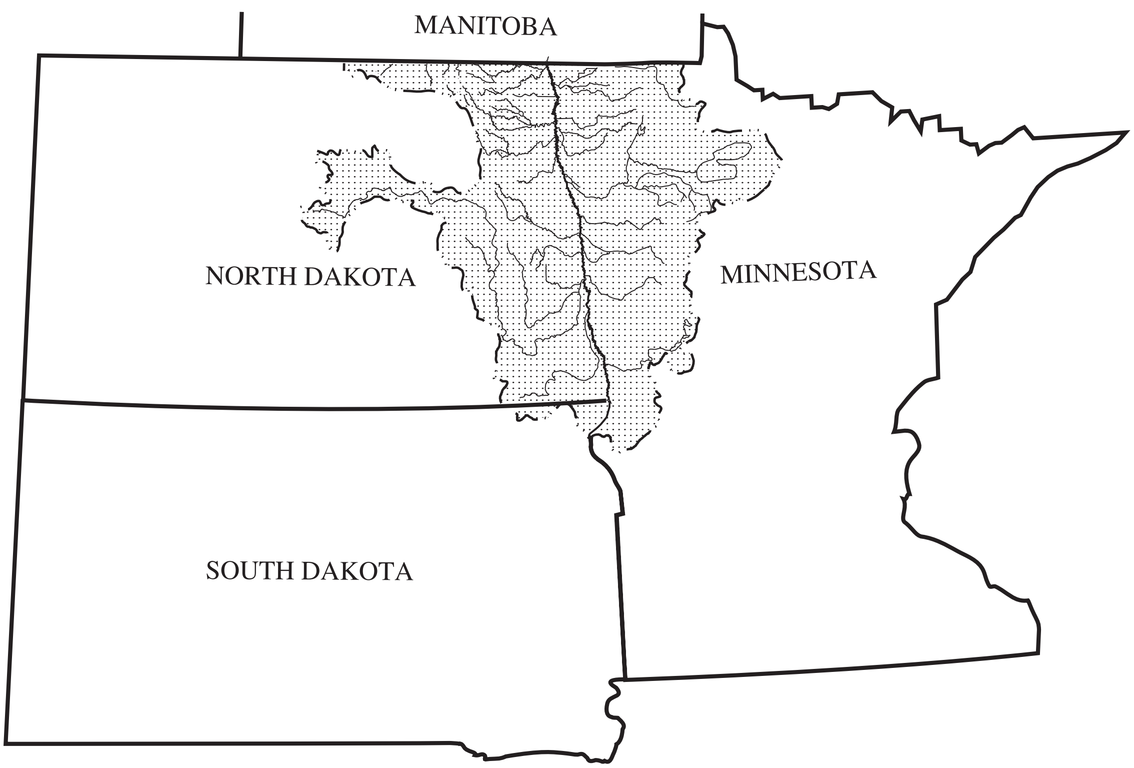
In cooperation with the Bureau of Reclamation

River Gain and Loss Studies for the Red River of the North Basin, North Dakota and Minnesota

Open-File Report 2004-1076



U.S. Department of the Interior
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River Gain and Loss Studies for the Red River of the North Basin, North Dakota and Minnesota

By Tara Williams-Sether

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In cooperation with the Bureau of Reclamation

Bismarck, North Dakota
2004

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By Tara Williams-Sether

Abstract

The Dakota Water Resources Act passed by the U.S. Congress in 2000 authorized the Secretary of the Interior to conduct a comprehensive study of future water-quantity and -quality needs of the Red River of the North (Red River) Basin in North Dakota and of possible options to meet those water needs. To obtain the river gain and loss information needed to properly account for available streamflow within the basin, available river gain and loss studies for the Sheyenne, Turtle, Forest, and Park Rivers in North Dakota and the Wild Rice, Sand Hill, Clearwater, South Branch Buffalo, and Otter Tail Rivers in Minnesota were reviewed. Ground-water discharges for the Sheyenne River in a reach between Lisbon and Kindred, N. Dak., were about 28.8 cubic feet per second in 1963 and about 45.0 cubic feet per second in 1986. Estimated monthly net evaporation losses for additional flows to the Sheyenne River from the Missouri River ranged from 1.4 cubic feet per second in 1963 to 51.0 cubic feet per second in 1976. Maximum water losses for a reach between Harvey and West Fargo, N. Dak., for 1956-96 ranged from about 161 cubic feet per second for 1976 to about 248 cubic feet per second for 1977. Streamflow gains of 1 to 1.5 cubic feet per second per mile were estimated for the Wild Rice, Sand Hill, and Clearwater Rivers in Minnesota. The average ground-water discharge for a 5.2-mile reach of the Otter Tail River in Minnesota was about 14.1 cubic feet per second in August 1994. The same reach lost about 14.1 cubic feet per second between February 1994 and June 1994 and about 21.2 cubic feet per second between August 1994 and August 1995.

INTRODUCTION

The Dakota Water Resources Act passed by the U.S. Congress on December 15, 2000, authorized the Secretary of the Interior to conduct a comprehensive study of future water-quantity and -quality needs of the Red River of the North (Red River) Basin in North Dakota and of possible options to meet those water needs. The Red River receives most of its flow from its eastern tributaries because of regional patterns in precipitation, evapotranspiration, soils, and topography. Although streamflow in the river varies greatly, the highest streamflows generally occur in spring and early summer as a result of snowmelt, rain falling on melting snow, or heavy rain falling on saturated soils. Streamflows in the river during the remainder of the year generally are less than one-fourth of the average annual streamflow (Stoner and others, 1993).

Many glacial-drift and bedrock aquifers within the Red River Basin are connected hydraulically to rivers within the basin. The most evident connections occur where surficial aquifers are crossed by rivers and the rivers receive direct ground-water discharge. The rivers within the basin tend to receive ground water from glacial-drift aquifers in upland moraine areas but have a reduced tendency to gain flow from ground water in the Red River Valley Lake Plain. The rivers that cross the Red River Valley Lake Plain generally lose water during the summer, possibly as a result of evaporation, but also have the potential to gain small amounts of water indirectly from regional bedrock aquifers that underlie the valley. The water is gained through glacial drift, wetlands, and flowing wells (Stoner and others, 1993). The amount of water gained by or lost from rivers within the Red River Basin also can be altered by climatic factors, such as droughts and wet periods, that affect the hydrologic responses of the rivers.

To obtain the river gain and loss information needed to properly account for available streamflow within the Red River Basin, the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, which administrates the comprehensive study authorized by the Dakota Water Resources Act, reviewed available river gain and loss studies for the basin. This report presents an overview of the studies that were reviewed and summarizes part of the gain and loss information given in those studies. The gain and loss information can be used to design and plan potential water-delivery systems to meet future water needs of the Red River Basin.

RIVER GAIN AND LOSS STUDIES FOR THE SHEYENNE RIVER

The Sheyenne River, a major tributary to the Red River, is limited to North Dakota. The river has a drainage area of about 6,910 square miles (not including the closed Devils Lake Basin) and is about 500 miles long. From its headwaters near Harvey, N. Dak., the river flows east to Pekin, N. Dak., south to Lisbon, N. Dak., and then northeast to its confluence with the Red River north of Fargo, N. Dak. (Souris-Red-Rainy River Basins Commission, 1972, p. D-50).

The Sheyenne River Basin lies in two distinct physiographic areas in North Dakota (fig. 1). The Drift Prairie area extends from the headwaters to near Lisbon, and the Red River Valley Lake Plain area extends from near Lisbon to the confluence of the Sheyenne River with the Red River. A hilly delta topography exists from Valley City, N. Dak., to near Kindred, N. Dak. Most of the Sheyenne River Valley from the headwaters to Kindred is incised into glacial till. The valley from Sheyenne, N. Dak., to Kindred ranges from 100 to 200 feet in depth and from 0.2 to 2 miles in width. The average gradient of the river is 1.5 feet per mile in the Drift Prairie and hilly delta areas and about 1 foot per mile in the Red River Valley Lake Plain area.

Zero streamflow has been recorded at times in the upper reaches of the Sheyenne River. Streamflow in the lower reaches of the river is regulated partly by releases from Baldhill Dam, which began operation in 1949. Lake Ashtabula, formed by Baldhill Dam, has a storage capacity of 69,100 acre-feet between the invert of the outlet conduit and the normal pool elevation. Lake Ashtabula is operated for flood control, municipal water supply, recreation, and stream-pollution abatement through low-flow augmentation. The capacity of Lake Ashtabula at the maximum pool elevation of 1,273.2 feet above the North American Vertical Datum of 1988 is 116,500 acre-feet.

Paulson (1964) investigated geologic factors that affect ground-water discharge for the Sheyenne River and indicated ground-water discharge was about 28.8 cubic feet per second from September 13 through November 19, 1963, in a reach of 94 river miles between Lisbon and Kindred. Mean monthly streamflow for selected sites on the Sheyenne River for October through February 1957-62 is listed in table 1 at the back of this report, and streamflow for the Sheyenne River between Valley City and West Fargo, N. Dak., for September 13 through November 19, 1963, is listed in table 2 at the back of this report. The locations of the streamflow-measurement sites used in Paulson (1964) are shown in figure 2. Paulson (1983) reported that if a gain of ground-water discharge and streamflow releases from Lake Ashtabula did not occur, little streamflow would be contributed from the Sheyenne River to the Red River except during periods of high surface runoff.

Guenthner (1991) reported ground-water discharges for two reaches of the Sheyenne River. Near Warwick, N. Dak. (from site 05055500 to site 9; fig. 2), ground-water discharge was 14.4 cubic feet per second on October 15 and 16, 1986. Between site A near Lisbon and site L near Kindred, ground-water discharge was about 45.0 cubic feet per second on October 21 and 22, 1986. Streamflow for selected sites on the Sheyenne River for October 1986 is listed in table 3 at the back of this report. The locations of the streamflow-measurement sites used in Guenthner (1991) are shown in figure 2.

Guenthner (1993) investigated the effects of transporting Missouri River water via the Garrison Diversion Unit on the Sheyenne River and the Red River and estimated monthly net evaporation (evaporation minus precipitation) losses for the additional flows to the system. Net evaporation losses estimated for the additional flows for 1931-84 ranged from 1.4 cubic feet per second in January 1963 to 51.0 cubic feet per second in August 1976 (table 4 at the back of this report). Other water losses, such as those caused by infiltration and bank storage, were not determined.

Houston Engineering, Inc. (1997), presented a hydrologic assessment of water losses in the Sheyenne River by seepage and evaporation. Some of the results obtained in the assessment also were presented by Gu and Deutschman (2001). The hydrologically based methods used to estimate the water losses were the long-term hydrologic budget method, the hydrograph (short-term water balance) method, and the statistical (an autocorrelation analysis) method. The long-term hydrologic budget method was performed year by year and month by month for the Sheyenne River by using data available for 1943-96. Results obtained with the long-term year-by-year hydrologic budget method are listed in table 5 at the back of this report. The long-term mean water loss of about 38.6 cubic feet per second from Harvey to West Fargo was determined by using data available for 1956-96 and applying an evapotranspiration coefficient of 0.94. Because water losses are affected by soil-moisture and ground-water table conditions, which, in turn, are affected by precipitation, Houston Engineering, Inc. (1997), used the current year's precipitation in the long-term hydrologic budget method to determine maximum water losses of about 200 cubic feet per second for 1964 and about 248 cubic feet per second for 1977 between Harvey and West Fargo. Using the previous year's precipitation in the long-term hydrologic budget method, the maximum

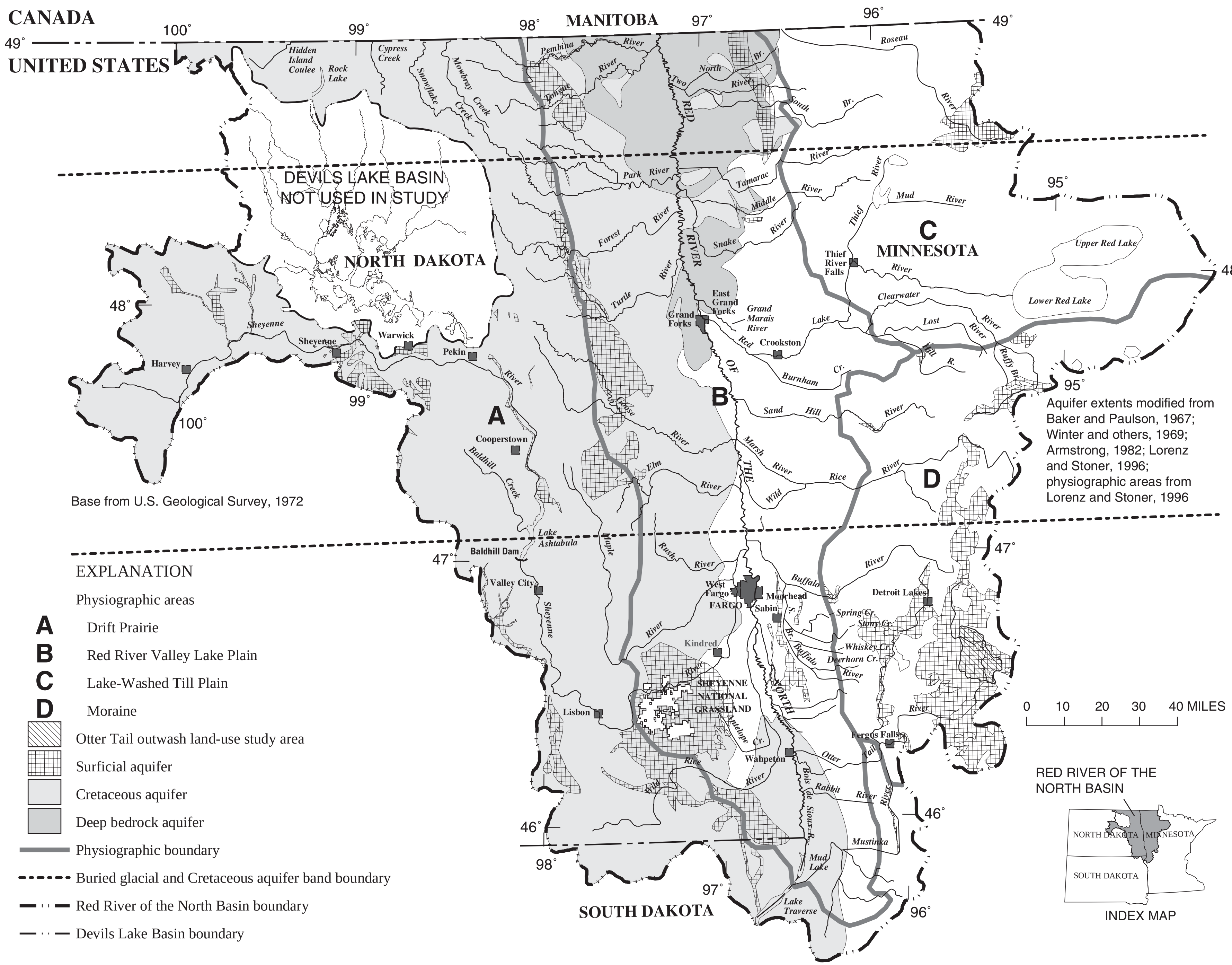


Figure 1. Locations of aquifers and physiographic areas in the Red River of the North Basin, North Dakota and Minnesota. (Modified from Cowdery, 1998.)

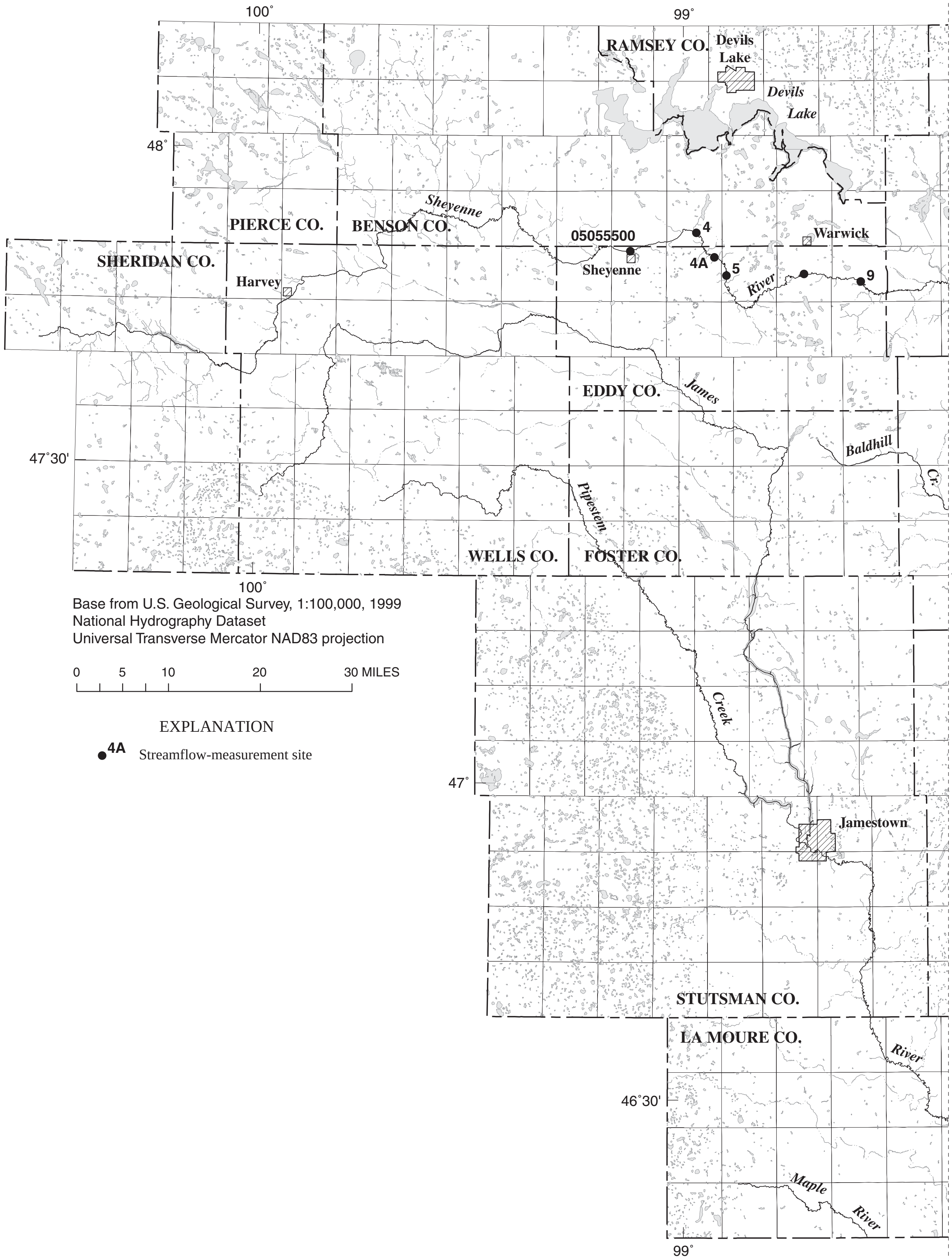
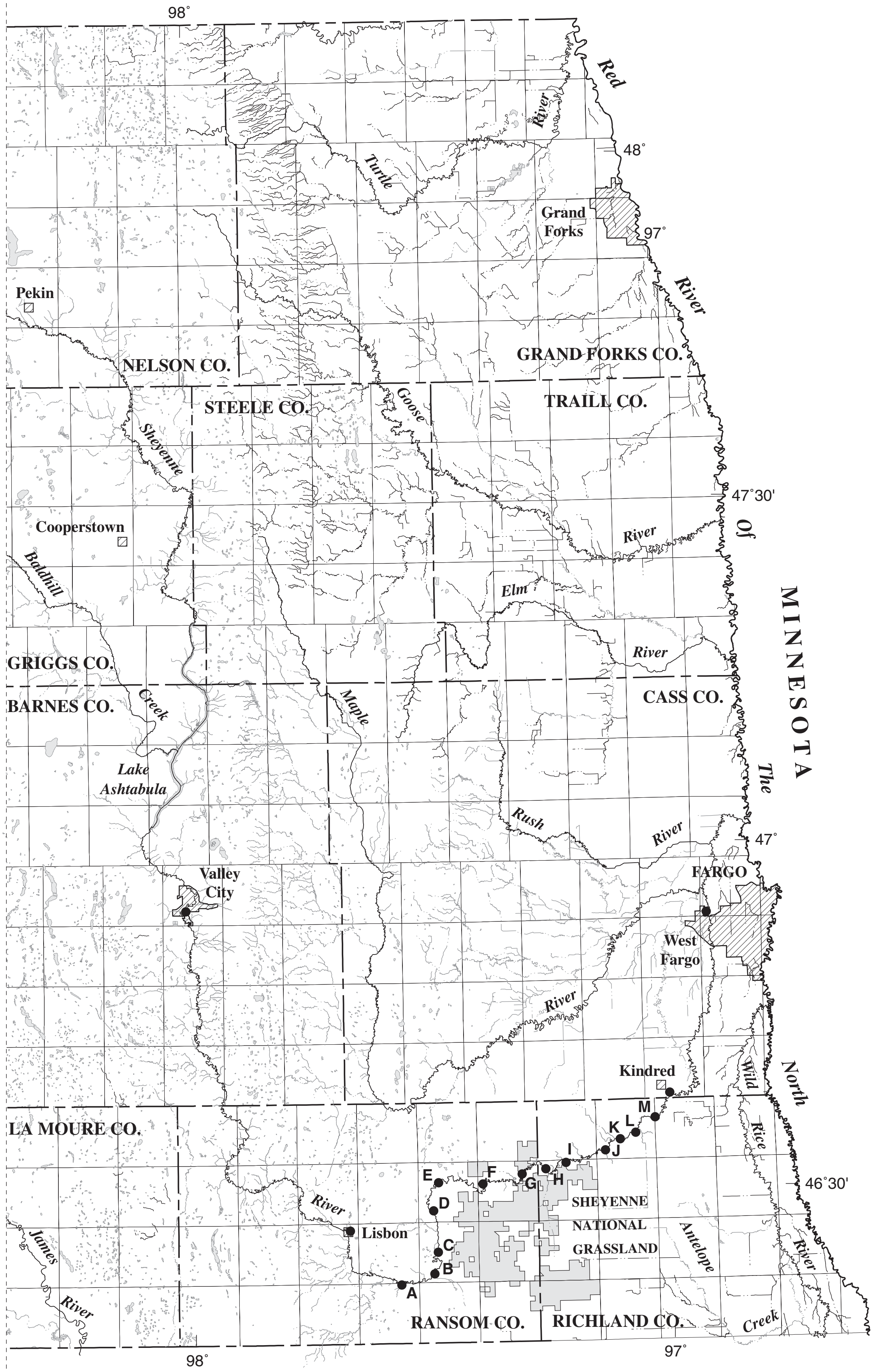


Figure 2. Locations of streamflow-measurement sites used in Paulson (1964) and Guenthner (1991) to determine ground-water



discharge to the Sheyenne River in North Dakota.

water losses were about 236 cubic feet per second for 1963 and about 161 cubic feet per second for 1976. Precipitation amounts were minimal for both of those years. A maximum water loss of about 60 cubic feet per second between Warwick and Cooperstown, N. Dak., was determined for 1964. Results of the long-term month-by-month hydrologic budget method indicated that water losses generally occurred during June through October and ranged from 126 to 277 cubic feet per second. The largest losses occurred during June and July. The Sheyenne River has a gaining reach from Harvey to Cooperstown, primarily during April, and a losing reach from Cooperstown to West Fargo, primarily during June through October. Main-channel water losses occurred between Cooperstown and Lisbon (fig. 3). The hydrograph method was

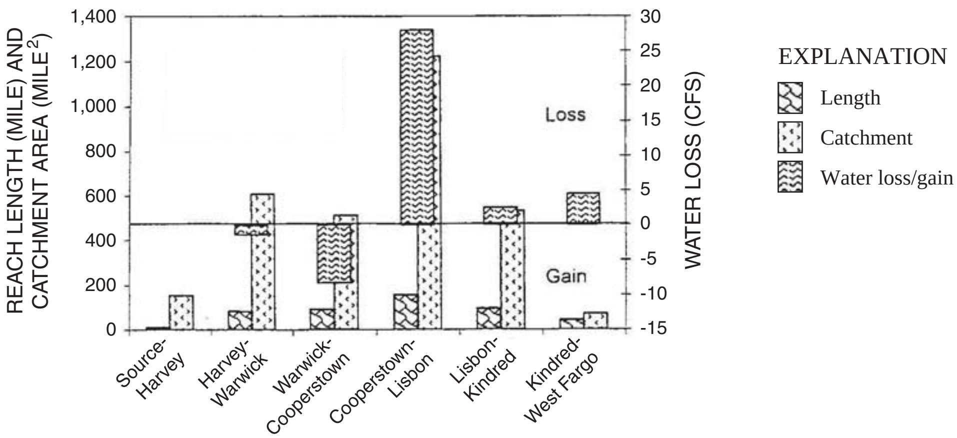


Figure 3. Mean water losses estimated for the Sheyenne River in North Dakota using the long-term year-by-year hydrologic budget method, 1943-96. (Modified from Gu and Deutschman, 2001.)

limited to periods of no rain and did not account for runoff. Results obtained with the hydrograph method are listed in table 6 at the back of this report for selected Sheyenne River reaches. The statistical method (an autocorrelation analysis) was applied to the Sheyenne River reach between Kindred and West Fargo for selected time periods. Statistics for the autocorrelation analysis for the reach between Kindred and West Fargo are listed in table 7 at the back of this report. Water losses estimated with the long-term hydrologic budget method, the hydrograph method, and the statistical method are listed in table 8 at the back of this report. The hydrograph and statistical methods underestimated water losses because precipitation and runoff were not considered (Houston Engineering, Inc., 1997). However, the contribution of precipitation and runoff to streamflow was considered in the long-term hydrologic budget method.

Strobel and Radig (1997) investigated the effects of the 1993 flood on water levels in the Sheyenne Delta aquifer. They concluded that, although no estimates of ground-water discharge were made, high stage within the Sheyenne River during July and August 1993 possibly caused water-table gradients near the river to reverse, and water from the river flowed into the aquifer as temporary bank storage.

RIVER GAIN AND LOSS STUDIES FOR OTHER RIVERS

Maclay and others (1972) estimated streamflow gains of 1 to 1.5 cubic feet per second per mile where the Wild Rice, Sand Hill, and Clearwater Rivers in Minnesota flowed through surficial outwash, ice contact, and beach-ridge sand and gravel aquifers. Streamflow losses were reported for an 11-mile reach of the South Branch Buffalo River downstream from Sabin, Minn., where pumpage from the Moorhead, Minn., municipal well field withdraws ground water from the Buffalo aquifer located beneath the river and for a 22-mile reach of the South Branch Buffalo River from Deerhorn Creek, Minn., to 5 miles downstream from Whiskey Creek, Minn.

Strobel and Gerla (1992) investigated the effects of saline ground-water discharge on water quality of the Red River in northeastern North Dakota. Estimated ground-water discharges for sites on the Turtle, Forest, and Park Rivers in North Dakota (fig. 4) were not reported but can be estimated using the recorded streamflow measurements listed in table 9 at the back of this report for October through December 1991.

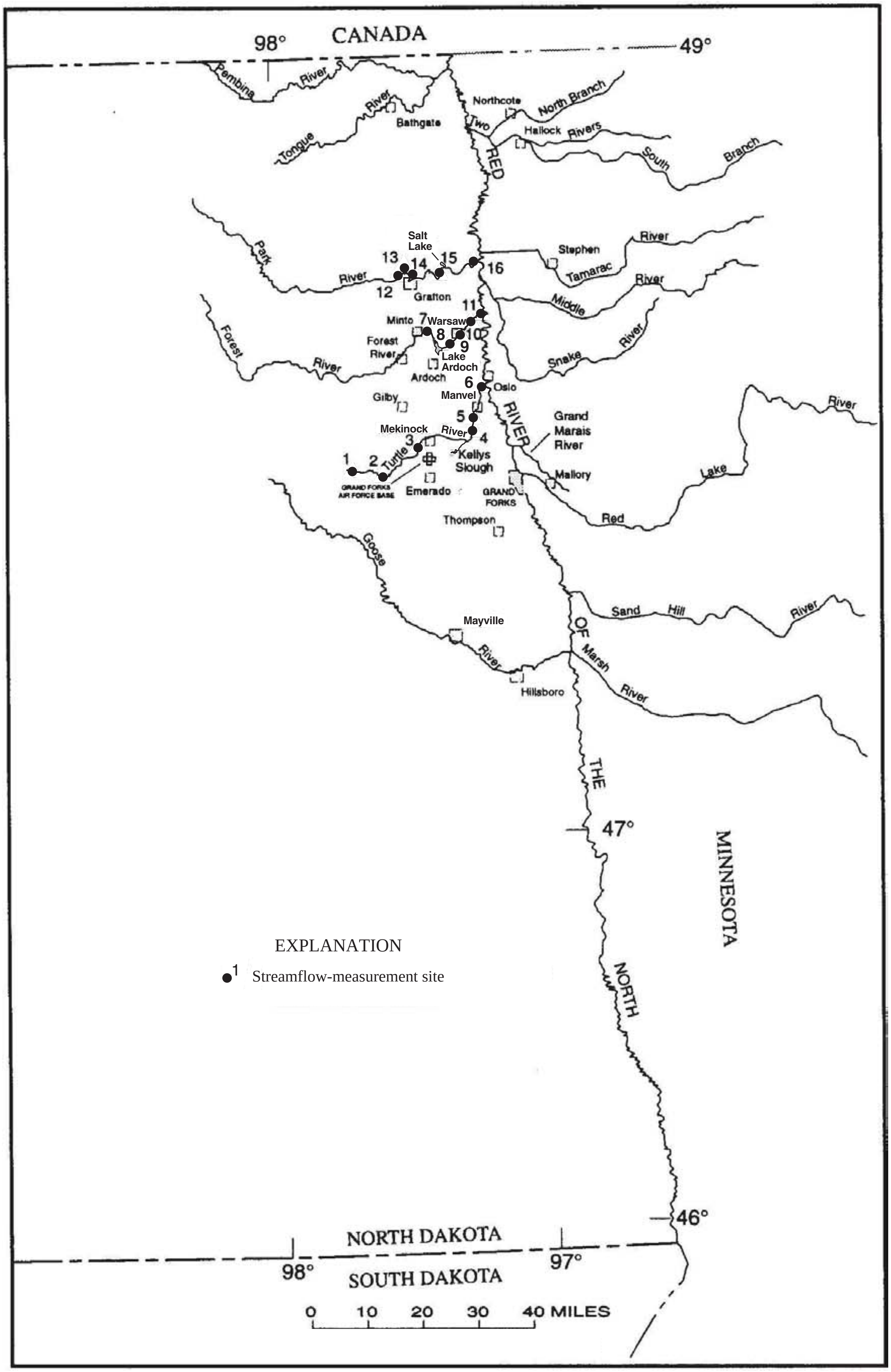


Figure 4. Locations of streamflow-measurement sites in North Dakota. (Modified from Strobel and Gerla, 1992.)

Strobel (1996) investigated the hydrologic factors that affect ground-water discharge in the Red River Basin in northeastern North Dakota and used some of the data from the 1992 study. Estimated ground-water discharges were not reported in the 1996 study, but Strobel (1996) indicated that many known and unknown free-flowing wells within the Red River Basin contributed to streamflow. The amount of streamflow contributed by the wells and the effects of the contribution on the hydrology and hydraulics of the basin are not known.

Puckett and others (2002) investigated the effects of the Otter Tail outwash aquifer on streamflows in the Otter Tail River in Minnesota. The investigation was part of a study to delineate redox processes and flow paths in the riparian zone of a glacial-outwash aquifer. Streamflow measurements were made during February through August 1994 and during August 1995 at three sites on the Otter Tail River (fig. 5; table 10 at the back of this report). Changes in streamflow

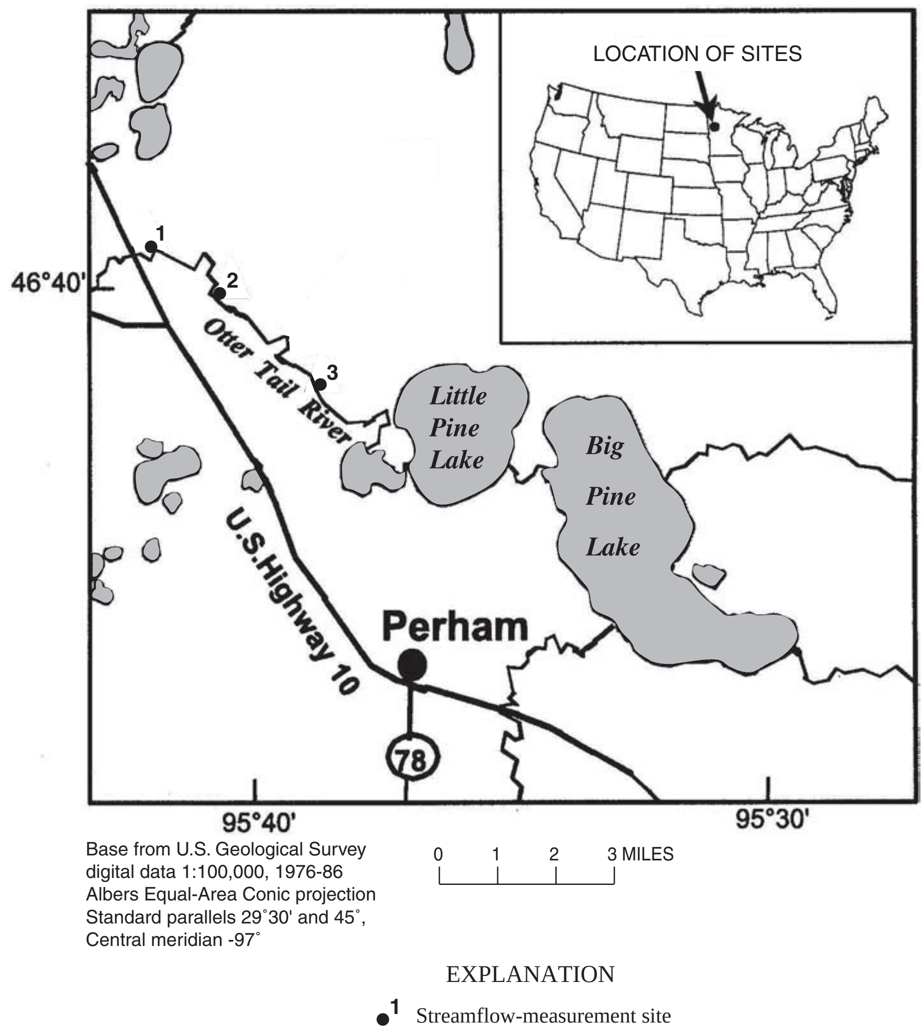


Figure 5. Locations of streamflow-measurement sites on the Otter Tail River in Minnesota. (Modified from Puckett and others, 2002.)

between the measurement sites are listed in table 10. The August sampling was conducted on the last day of the month at the end of the growing season when evapotranspiration losses may have been greatly reduced. Therefore, the increases in streamflow during what were typically low-flow periods are what would be expected for a river that gains streamflow from ground-water discharge. Puckett and others (2002) indicated that within a 5.2-mile reach of the Otter Tail River, the average ground-water discharge was about 14.1 cubic feet per second (0.4 cubic meter per second) in August 1994. Puckett and others (2002) also indicated that, by assuming the ground-water discharge was relatively constant, the same reach lost about 14.1 cubic feet per second (0.4 cubic meter per second) between February 1994 and June 1994 and about 21.2 cubic feet per second (0.6 cubic meter per second) between August 1994 and August 1995.

SUMMARY

The Dakota Water Resources Act passed by the U.S. Congress in 2000 authorized the Secretary of the Interior to conduct a comprehensive study of future water-quantity and -quality needs of the Red River of the North (Red River) Basin in North Dakota and of possible options to meet those water needs. To obtain the river gain and loss information needed to properly account for available streamflow within the basin, available river gain and loss studies for the Sheyenne, Turtle, Forest, and Park Rivers in North Dakota and the Wild Rice, Sand Hill, Clearwater, South Branch Buffalo, and Otter Tail Rivers in Minnesota were reviewed. This report presents an overview of the studies that were reviewed and summarizes part of the gain and loss information given in those studies. The gain and loss information can be used to design and plan potential water-delivery systems to meet future water needs of the Red River Basin.

Ground-water discharges for the Sheyenne River in a reach between Lisbon and Kindred, N. Dak., were about 28.8 cubic feet per second in 1963 and about 45.0 cubic feet per second in 1986. Ground-water discharge near Warwick, N. Dak., was 14.4 cubic feet per second in 1986. Estimated monthly net evaporation losses for additional flows to the Sheyenne River from the Missouri River ranged from 1.4 cubic feet per second in 1963 to 51.0 cubic feet per second in 1976. Using a long-term hydrologic budget method, a long-term mean water loss of about 38.6 cubic feet per second was determined for a reach between Harvey and West Fargo, N. Dak., for 1956-96. The maximum water losses for the reach were about 236 cubic feet per second for 1963, 200 cubic feet per second for 1964, 161 cubic feet per second for 1976, and 248 cubic feet per second for 1977. A maximum water loss of about 60 cubic feet per second between Warwick and Cooperstown, N. Dak., was determined for 1964. Water losses from the Sheyenne River generally occurred during June through October. The largest losses occurred during June and July.

Streamflow gains of 1 to 1.5 cubic feet per second per mile were estimated for the Wild Rice, Sand Hill, and Clearwater Rivers in Minnesota. Streamflow losses were reported for an 11-mile reach of the South Branch Buffalo River downstream from Sabin, Minn., and for a 22-mile reach of the South Branch Buffalo River from Deerhorn Creek, Minn., to 5 miles downstream from Whiskey Creek, Minn. Within a 5.2-mile reach of the Otter Tail River, the average ground-water discharge was about 14.1 cubic feet per second (0.4 cubic meter per second) in August 1994. The same reach lost about 14.1 cubic feet per second (0.4 cubic meter per second) between February 1994 and June 1994 and about 21.2 cubic feet per second (0.6 cubic meter per second) between August 1994 and August 1995.

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Table 1. Mean monthly streamflow for selected sites on the Sheyenne River in North Dakota, October through February 1957-62

[Modified from Paulson, 1964]

	Streamflow (cubic feet per second)
Valley City, N. Dak. (253 river miles above mouth)	
October	28.0
November	41.5
December	43.5
January	41.6
February	40.1
Average for 5-month period	38.9
Lisbon, N. Dak. (162 river miles above mouth)	
October	31.7
November	42.9
December	41.9
January	38.8
February	42.5
Average for 5-month period	[1]39.6
Kindred, N. Dak. (68 river miles above mouth)	
October	50.7
November	62.0
December	56.5
January	52.7
February	51.5
Average for 5-month period	[2]54.7
West Fargo, N. Dak. (24 river miles above mouth)	
October	52.6
November	61.0
December	59.3
January	54.4
February	52.6
Average for 5-month period	[3]55.9

[1]The average gain between Valley City and Lisbon, N. Dak., was 0.7 cubic foot per second; the average gain per mile of river between Valley City and Lisbon, N. Dak., was 0.008 cubic foot per second.

[2]The average gain between Lisbon and Kindred, N. Dak., was 15.1 cubic feet per second; the average gain per mile of river between Lisbon and Kindred, N. Dak., was 0.160 cubic foot per second.

[3]The average gain between Kindred and West Fargo, N. Dak., was 1.2 cubic feet per second; the average gain per mile of river between Kindred and West Fargo, N. Dak., was 0.027 cubic foot per second.

Table 2. Streamflow for the Sheyenne River between Valley City and West Fargo, North Dakota, September 13 through November 19, 1963

[Modified from Paulson, 1964; --, not estimated; -, indicates water loss]

Site	River mile	Streamflow (cubic feet per second)					Average streamflow for September 13 through November 19 (cubic feet per second)	Estimated ground-water discharge (cubic feet per second)
		September 13	October 1	October 15	October 29	November 19		
Valley City[1]	253.0	11.0	7.90	6.90	5.70	[2]33.0	7.87	--
Lisbon	162.0	6.98	6.22	11.4	13.7	[2]25.0	9.57	1.7
Site A	147.5	8.60	8.02	11.0	17.0	[2]21.4	11.1	1.5
Site B	141.6	10.3	8.96	13.2	19.3	[2]18.6	12.9	1.8
Site C	134.9	11.1	9.31	11.4	21.3	16.2	13.9	1.0
Site D	131.5	11.7	9.20	13.9	21.8	19.2	15.2	1.3
Site E	125.9	11.6	8.56	15.0	21.1	18.2	14.9	-.3
Site F	114.0	16.6	12.5	18.6	27.9	24.5	20.0	5.1
Site G	104.0	21.9	18.8	24.1	28.7	30.8	24.9	4.9
Site H	97.4	24.1	21.1	28.3	33.1	27.5	26.9	2.0
Site I	91.8	29.8	26.2	32.9	35.0	33.0	31.4	4.5
Site J	87.6	31.5	25.8	34.9	39.5	38.3	34.0	2.6
Site K	81.1	34.2	29.5	37.8	46.2	39.1	37.4	3.4
Site L	77.3	36.6	26.6	35.9	43.4	39.4	36.4	-1.0
Site M	73.6	34.5	28.8	37.2	41.4	42.0	36.8	.4
Near Kindred	68.1	33.5	31.0	37.8	46.1	43.8	38.4	1.6
West Fargo[1]	24.5	36.0	26.0	33.0	45.0	[2]54.0	35.0	-3.4

[1]Streamflow computed from gage-height record.

[2]Streamflow affected by releases from Lake Ashtabula. Not used in computing averages.

Table 3. Streamflow for selected sites on the Sheyenne River in North Dakota, October 1986

[Modified from Harkness and others, 1988; --, not estimated; -, indicates water loss]

Date	Time	Instantaneous streamflow (cubic feet per second)	Average streamflow (cubic feet per second)	Estimated ground-water discharge (cubic feet per second)
Sheyenne River at Sheyenne, N. Dak. (station number--05055500)				
October 15, 1986	1350	7.90		--
October 16, 1986	0955	.40	3.9	
October 16, 1986	1355	3.50		
Sheyenne River, site 4 (site identifier--4751480995754)				
October 15, 1986	1540	11.1		
October 16, 1986	1140	9.51	10.0	6.1
October 16, 1986	1545	9.55		
Sheyenne River, site 4A (site identifier--4750010985530)				
October 16, 1986	0930	11.4	10.6	0.6
October 16, 1986	1530	9.70		
Sheyenne River, site 5 (site identifier--4747550985323)				
October 15, 1986	1705	10.9		
October 16, 1986	1115	11.4	11.2	0.6
October 16, 1986	1530	11.3		
Sheyenne River, site 9 (site identifier--4746240983318)				
October 15, 1986	1615	18.0		
October 16, 1986	1105	19.1	18.3	7.1
October 16, 1986	1530	17.7		
Sheyenne River, site A (site identifier--4622020973347)				
October 21, 1986	1310	32.1		--
October 22, 1986	0935	30.6	31.0	
October 22, 1986	1230	30.4		
Sheyenne River, site C (site identifier--4625400972934)				
October 21, 1986	1425	36.4		
October 22, 1986	1045	35.1	35.6	4.6
October 22, 1986	1330	35.3		
Sheyenne River, site D (site identifier--4728180973003)				
October 21, 1986	1530	45.9		
October 22, 1986	1125	40.2	42.0	6.4
October 22, 1986	1430	39.9		
Sheyenne River, site E (site identifier--4630540972923)				
October 21, 1986	1420	39.8		
October 22, 1986	0920	38.6	39.3	-2.7
October 22, 1986	1325	39.5		
Sheyenne River, site F (site identifier--4630530972340)				
October 21, 1986	1600	45.4		
October 22, 1986	1100	47.7	46.7	7.4
October 22, 1986	1515	46.9		
Sheyenne River, site G (site identifier--4631290971847)				
October 21, 1986	1320	52.8		
October 22, 1986	0915	51.7	52.9	6.2
October 22, 1986	1250	54.2		
Sheyenne River, site H (site identifier--4631500971540)				
October 21, 1986	1455	54.5		
October 22, 1986	1100	55.7	55.1	2.2
October 22, 1986	1430	55.2		

Table 3. Streamflow for selected sites on the Sheyenne River in North Dakota, October 1986—Continued

[Modified from Harkness and others, 1988; --, not estimated; -, indicates water loss]

Date	Time	Instantaneous streamflow (cubic feet per second)	Average streamflow (cubic feet per second)	Estimated ground-water discharge (cubic feet per second)
Sheyenne River, site I (site identifier--4632210971306)				
October 21, 1986	1405	61.9		
October 22, 1986	0905	63.3	63.2	8.1
October 22, 1986	1640	64.4		
Sheyenne River, site J (site identifier--4633250970814)				
October 21, 1986	1230	68.4		
October 22, 1986	1155	67.9	68.1	4.9
October 22, 1986	1445	68.0		
Sheyenne River, site L (site identifier--4634530970428)				
October 21, 1986	1350	78.0		
October 22, 1986	0905	74.4	76.0	7.9
October 22, 1986	1315	75.6		

Table 4. Estimated monthly net evaporation losses for additional flows to the Sheyenne River in North Dakota, 1931-84

[Modified from Guenthner, 1993]

Month	Year of occurrence	Estimated net evaporation loss	
		Inches	Cubic feet per second
January	1963	0.21	1.4
February	1934	.28	2.1
March	1958	.66	4.5
April	1980	1.78	12.6
May	1980	6.66	45.6
June	1974	5.49	38.8
July	1936	7.21	49.4
August	1976	7.42	51.0
September	1948	5.68	40.2
October	1945	2.62	17.9
November	1939	.87	6.2
December	1939	.23	1.6

Table 5. Mean water losses estimated for the Sheyenne River in North Dakota using the long-term year-by-year hydrologic budget method, 1943-96

[Modified from Gu and Deutschman, 2001; c_1, evapotranspiration coefficient; -, indicates water gain]

	Period of record used	Reach length (miles)	Contributing area (square miles)	Water loss (cubic feet per second)			
				$c_1 = 0.925$	$c_1 = 0.93$	$c_1 = 0.94$	$c_1 = 0.95$
Warwick to Cooperstown, N. Dak.	1951-80	91	510	6	3	-3.7	-11
Harvey to West Fargo, N. Dak.	1956-96	465	3,090	99	79	38.6	-1.7

Table 6. Monthly mean water losses estimated for selected Sheyenne River reaches in North Dakota using the hydrograph method

[Modified from Houston Engineering, Inc., 1997]

Year	Month	Mean streamflow[1] (cubic feet per second)	Mean precipitation[2] (inch)	Monthly mean water loss (cubic feet per second)	Water loss over the reach (nondimensional)	Water loss over the reach per mile (nondimensional)
			Kindred to West Fargo, N. Dak. (43 miles)			
1956	November	47	1.52	4.04	0.086	0.0020
1956	December	59	.30	3.42	.058	.0013
1957	January	56	.31	15.74	.281	.0065
1957	February	58	.32	15.60	.269	.0063
1957	September	324	4.00	34.34	.106	.0025
1989	December	33	.19	2.20	.068	.0016
1990	January	25	.06	2.67	.107	.0025
1990	February	33	.48	6.90	.209	.0049
1990	March	92	1.64	22.82	.248	.0058
1990	April	107	1.60	15.73	.147	.0034
			Warwick to Cooperstown, N. Dak. (91 miles)			
1981	February	154	0.96	78.54	0.510	0.0056
1985	August	80	4.18	62.40	.780	.0086
1991	August	15	1.65	4.28	.285	.0031
1991	September	22	3.35	7.11	.323	.0025

[1]The long-term average streamflows are 225 cubic feet per second at Kindred, N. Dak., and 59 cubic feet per second at Warwick, N. Dak.

[2]The long-term mean monthly precipitation amount is 1.525 inches.

Table 7. Statistics of the autocorrelation analysis (statistical method) for the Sheyenne River reach between Kindred and West Fargo, North Dakota

[Data from Houston Engineering, Inc., 1997; lag, streamflow traveltime from upstream (Kindred) to downstream (West Fargo); r, maximum correlation coefficient corresponding to lag; Q_{ds}, streamflow downstream; c, regression equation coefficient; Q_{us}, streamflow upstream; d, regression equation coefficient; R^2, coefficient of determination]

Period	Autocorrelation		Regression		
	Lag (days)	r	$Q_{ds} = c(Q_{us})^d$		R^2
			c	d	
October 1, 1956, through February 13, 1957	2	0.756	3.39	0.65	0.708
February 14, 1957, through August 19, 1957	2	.806	.736	1.08	.673
August 20, 1957, through December 25, 1957	2	.977	2.25	.845	.943
May 1, 1989, through December 31, 1989	1	.901	.868	1.06	.814
January 1, 1990, through December 31, 1990	2	.909	1.531	.872	.891
January 1, 1991, through February 18, 1992	2	.853	1.718	.845	.717

Table 8. Estimated water losses for the Sheyenne River reach between Kindred and West Fargo, North Dakota

[Data from Houston Engineering, Inc., 1997; c_1, evapotranspiration coefficient; -, indicates water gain]

Period	Average streamflow[1] (cubic feet per second)	Water loss (cubic feet per second)		
		Long-term hydrologic budget method ($c_1 = 0.94$)	Hydrograph method	Statistical method
October 1, 1956, through February 13, 1957	47	7.7	5.21	5.75
February 14, 1957, through August 19, 1957	96	-4.7	-9.7	-5.8
August 20, 1957, through December 25, 1957	173	1.1	-1.43	-2.12
May 1, 1989, through December 31, 1989	53	-.9	-5.3	-6.47
January 1, 1990, through December 31, 1990	52	9.2	4.6	3.95
January 1, 1991, through February 18, 1992	51	9.3	2.4	3.32

[1]The long-term average streamflow at Kindred, N. Dak., is 225 cubic feet per second.

Table 9. Streamflow for selected sites on the Turtle, Forest, and Park Rivers in North Dakota, October through December 1991

[Modified from Strobel and Gerla, 1992]

Date of measurement	Streamflow (cubic feet per second)	Date of measurement	Streamflow (cubic feet per second)
Turtle River, site 1		**Forest River at Minto, N. Dak., site 7**	
December 10	1.4	December 10	10
Turtle River, site 2		**Forest River at Lake Ardoch, site 8**	
October 11	4.4	October 11	21
November 4	8.7	November 29	20
December 10	5.9	December 10	12
Turtle River at Mekinock, N. Dak., site 3		**Forest River at mouth, site 11**	
October 11	3.8	October 11	34
November 4	9.1	November 29	20
December 10	7.7	December 10	12
Turtle River at Manvel, N. Dak., site 4		**Park River, site 15**	
October 11	3.6	December 11	8.8
Turtle River below Manvel, N. Dak., site 5		**Park River at mouth, site 16**	
December 10	5.1	December 11	8.4
Turtle River at mouth, site 6			
November 4	37		
December 10	6.6		

Table 10. Streamflow and changes in streamflow for sites on the Otter Tail River in Minnesota

[Modified from Puckett and others, 2002; --, no data]

Date	Streamflow (cubic meters per second)					
	Site 1	Site 2	Upstream net change	Site 3	Downstream net change	Total change
February 1994	2.1	--	--	2.5	0.4	0.4
June 1994	5.0	5.0	0	5.0	0	0
August 1994	2.6	2.8	.2	3.0	.2	.4
August 1995	2.1	2.1	0	1.9	-.2	-.2