

**Prepared in cooperation with the North Dakota Department of Water Resources, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers, St. Paul District**

# **Measurements of Streamflow Gain and Loss on the Souris River between Lake Darling and Verendrye, North Dakota, August 31 and September 1, 2021**

Open-File Report 2022–1005



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**U.S. Department of the Interior**  
**U.S. Geological Survey**

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## Contents

Acknowledgments .....	iii
Abstract .....	1
Introduction.....	1
Purpose and Scope .....	3
Methods.....	3
Streamflow Gains and Losses on the Souris River .....	3
References Cited.....	10

## Figures

1. Study area map showing measurement locations on the Souris River between Lake Darling and Verendrye, North Dakota.....	2
2. Graph showing daily mean streamflow for the U.S. Geological Survey streamgages on the Souris River near Foxholm, North Dakota, Souris River above Minot, N. Dak., and Souris River near Verendrye, N. Dak., October 1, 2020, through September 30, 2021.....	4
3. Graphs showing monthly precipitation and air temperature for Minot, North Dakota, and monthly streamflow for the U.S. Geological Survey streamgage Souris River above Minot, N. Dak., September 2016 through September 2021.....	5
4. Graph showing measured streamflow at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota, and Souris River near Verendrye, N. Dak., August 31 and September 1, 2021.....	6

## Tables

1. Streamflow measurements made at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota, and Souris River near Verendrye, N. Dak., August 31 and September 1, 2021.....	7
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## Conversion Factors

U.S. customary units to International System of Units

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
<b>Area</b>		
square mile (mi <sup>2</sup> )	259.0	hectare (ha)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
<b>Flow rate</b>		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8.$$

## Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

## Abbreviations

USGS      U.S. Geological Survey



# Measurements of Streamflow Gain and Loss on the Souris River between Lake Darling and Verendrye, North Dakota, August 31 and September 1, 2021

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## Abstract

Dry conditions during 2020 and 2021 affected the water supply within the Souris River Basin and highlighted the need for better understanding of the streamflow dynamics for managing the resource during low-flow conditions. In June 2021, a loss of streamflow was observed on the Souris River between U.S. Geological Survey streamgages on the Souris River near Foxholm, North Dakota (site 1), and near Verendrye, N. Dak. (site 22). The largest loss was upstream from the Souris River above Minot, N. Dak. (site 7). On June 6, 2021, the daily mean streamflow decreased from 33.8 cubic feet per second at site 1 to 16.3 cubic feet per second at site 7, a loss of 17.5 cubic feet per second. To better understand where streamflow losses occurred in the reach from site 1 to site 22, multiple sites were selected for streamflow measurements between the three streamgages (sites 1, 7, and 22). Streamflow measurements made at 22 selected sites on the Souris River on August 31 and September 1, 2021, did not indicate the loss in streamflow that was observed at the three streamgages (sites 1, 7, and 22) in June 2021. Measurements made at the three streamgages (sites 1, 7, and 22) on August 31 had streamflows of 44.2, 45.9, and 46.8 cubic feet per second, respectively. Streamflow measured at all 22 sites on August 31 and September 1 on the Souris River ranged from 38.4 (site 9) to 49.8 cubic feet per second (site 12). In general, the largest change in streamflow was measured among sites on the Souris River in or near the city of Minot, N. Dak.

## Introduction

The Souris River Basin is a 24,600 square mile international basin in southeast Saskatchewan, north-central North Dakota and southwest Manitoba (fig. 1). Since 1940, Canada and the United States have worked together through the International Joint Commission to jointly manage the transboundary waters of the Souris River. The waters of the Souris River Basin are extensively managed for flood control and water supply by dams, diversion canals, and water resource infrastructure to meet the needs

of communities, agriculture, industry, recreation, and ecosystems. The flow upstream from Minot, North Dakota, is affected by regulation from the Rafferty, Grant Devine, and Boundary Reservoirs in Saskatchewan (not shown) and Lake Darling in North Dakota (fig. 1), which are operated in accordance with an international agreement between Canada and the United States (United Nations, 1989).

Dry conditions during 2020 and 2021 affected the water supply within the Souris River Basin and highlighted the need for better understanding of the streamflow dynamics for managing the resource during low-flow conditions. An international agreement outlines that a minimum streamflow of 20 cubic feet per second ( $\text{ft}^3/\text{s}$ ) in the Souris River be delivered to Manitoba at the International border near Westhope, N. Dak. (fig. 1), from June through October (United Nations, 1989). In an attempt to comply with the international agreement, the U.S. Fish and Wildlife Service, who manages the National Wildlife Refuges at Lake Darling and J. Clark Salyer Pool (fig. 1), adjusted releases from Lake Darling to deliver sufficient water to J. Clark Salyer Pool in 2021. During these releases, a loss of streamflow volume was observed between the U.S. Geological Survey (USGS) streamgages on the Souris River near Foxholm, N. Dak. (site 1; USGS station 05116000; fig. 1), and above Minot, N. Dak. (site 7; USGS station 05117500; fig. 1).

Several glacial and alluvial groundwater aquifer units intersect with the Souris River in the reach between the USGS streamgages near Foxholm, N. Dak. (site 1), and near Verendrye, N. Dak. (site 22; fig. 1), and several water-supply withdrawals (not shown) are permitted along the reach. Flow also is added by the discharge from the city of Minot wastewater treatment plant (site 15). An understanding of streamflow gains and losses along the reach and the possible causes of the streamflow changes are important for managing the Souris River to meet various water supply demands.

To determine where streamflow gains and losses were along the Souris River, the USGS in cooperation with the North Dakota Department of Water Resources; U.S. Fish and Wildlife Service; and the U.S. Army Corps of Engineers, St. Paul District, made streamflow measurements at selected locations between the USGS streamgages on the Souris River near Foxholm, N. Dak., and near Verendrye, N. Dak., on August 31 and September 1, 2021 (sites 1 and 22, respectively; fig. 1).

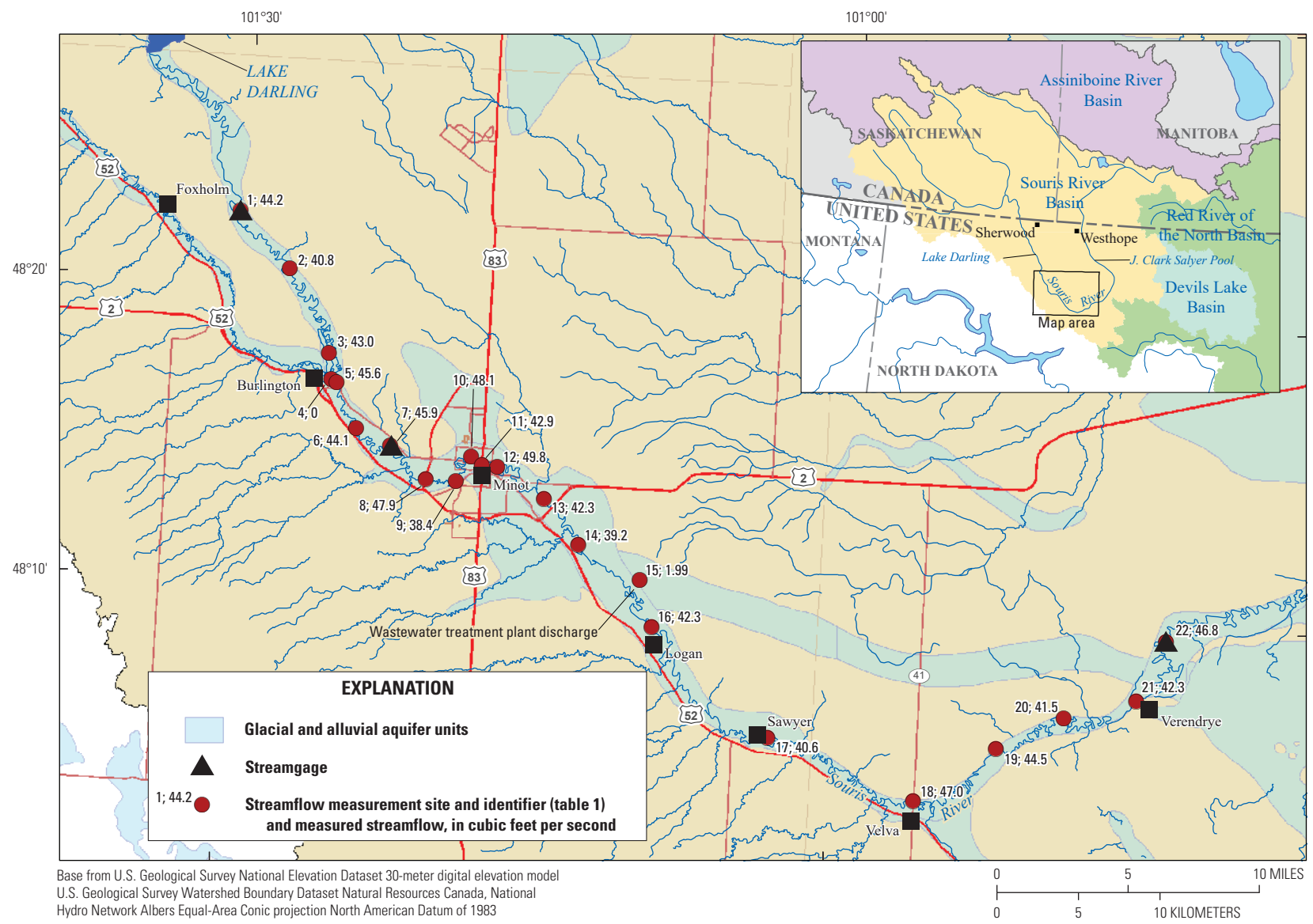


Figure 1. Study area map showing measurement locations on the Souris River between Lake Darling and Verendrye, North Dakota.

## Purpose and Scope

The purpose of this report is to describe streamflow measurements made downstream from Lake Darling between the USGS streamgages on the Souris River near Foxholm, N. Dak. (site 1), and the Souris River near Verendrye, N. Dak. (site 22), to determine where streamflow gains and losses occur during low-flow conditions. Measurements were made at 22 selected locations on August 31 and September 1, 2021.

## Methods

Streamflow measurements were made during a period of stable conditions in the reach of the Souris River from the USGS streamgage near Foxholm, N. Dak. (site 1), to the Souris River near Verendrye, N. Dak. (site 22). Measurements were made when the U.S. Fish and Wildlife Service could hold the releases from Lake Darling steady at a streamflow of about 40 ft<sup>3</sup>/s and there was an extended period of no rainfall.

Sites were selected based on locations of existing streamgages, locations of surficial aquifer units, locations of permitted water withdrawals (not shown), and discharges such as the Minot wastewater treatment plant discharge point (fig. 1). Exact locations of permitted withdrawal points were not known, only general locations within the reach. Tributary inflows also were measured if any flow was observed. Streamflow measurements were made using acoustic Doppler velocimeters or acoustic Doppler current profilers following methods described in Turnipseed and Sauer (2010) and Mueller and others (2013). Measurements were processed following methods described in Mueller (2016). For sites with a relatively substantial change in streamflow between measurement locations, multiple measurements were made to verify the differences in streamflow. All streamflow measurement data are available from the USGS National Water Information System web page (U.S. Geological Survey, 2021). Most sites, except for sites 9, 12, and 15, were measured on August 31, 2021. Streamflow measurements were made at sites 9, 12, and 15 on September 1, 2021. Sites 10, 11, and 14 were remeasured on September 1, 2021, to verify the results of the measurements on the previous day.

Streamflow gains and losses were determined by computing the difference in streamflow between adjacent locations. Relative percent differences were computed to compare differences in streamflow between adjacent sites to the relative uncertainty of the measurements. In general, streamflow measurement uncertainty is a qualitative rating by the individual making the measurement based on conditions such as the variability of the channel at the measuring section, velocity conditions, equipment function, rapidly changing stage conditions, ice cover, and wind conditions (Turnipseed and Sauer, 2010). Measurements are rated either excellent, good, fair, or poor with uncertainties of about 2, 5, 8, and greater than 8 percent of the measured streamflow, respectively (Turnipseed and Sauer, 2010).

## Streamflow Gains and Losses on the Souris River

In June 2021, a loss of streamflow was observed on the Souris River between the USGS streamgages near Foxholm, N. Dak. (site 1), and near Verendrye, N. Dak. (site 22; figs. 1 and 2). The largest loss was upstream from the Souris River above Minot, N. Dak. (site 7; figs. 1 and 2). On June 6, 2021, the daily mean streamflow decreased from 33.8 ft<sup>3</sup>/s at site 1 to 16.3 ft<sup>3</sup>/s at site 7, a loss of 17.5 ft<sup>3</sup>/s. Streamflow increased downstream from site 7 to 26.4 ft<sup>3</sup>/s at site 22 on June 6 (figs. 1 and 2).

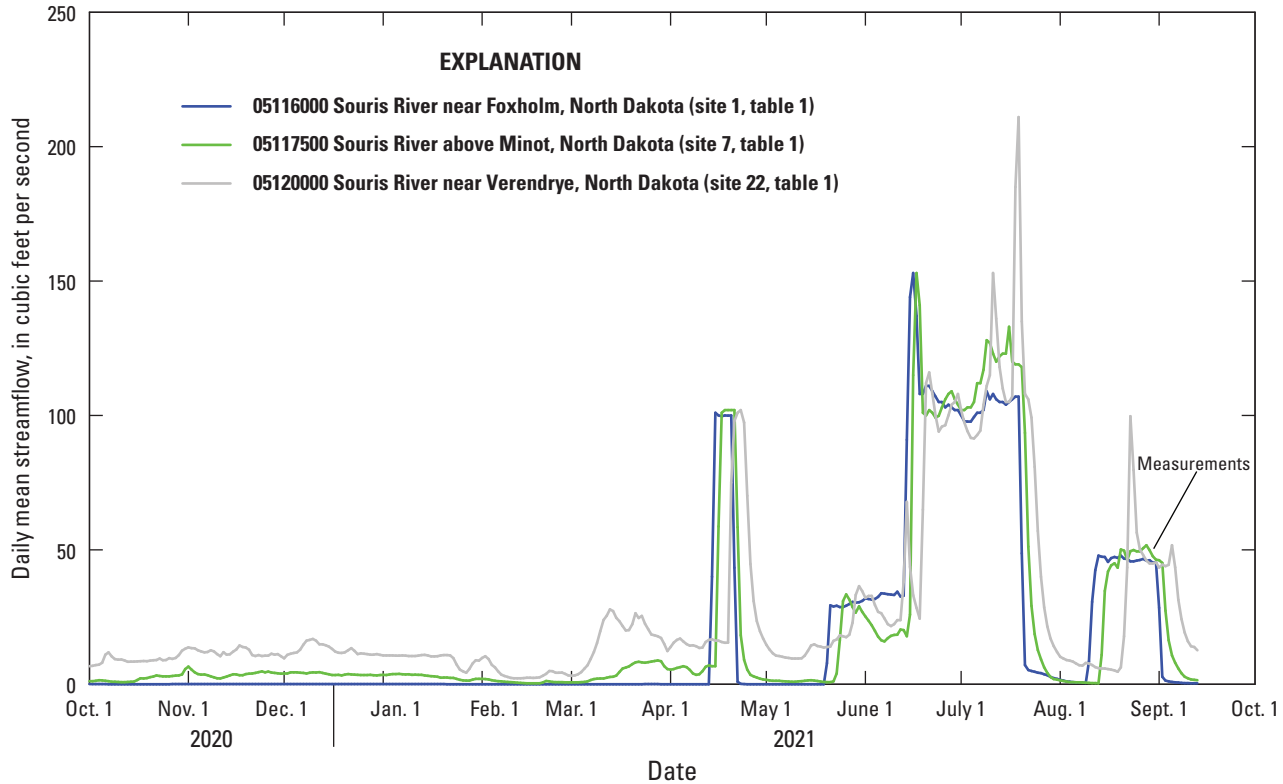
Preceding dry and warm conditions in the basin likely contributed to the loss of streamflow between the Souris River near Foxholm, N. Dak. (site 1), and Souris River above Minot, N. Dak. (site 7), in early June 2021 (fig. 2). Precipitation was less than the long-term mean monthly precipitation at Minot in the preceding 8 months, and air temperatures were mostly greater than the long-term mean monthly temperatures, resulting in not much runoff. Monthly streamflows were less than the long-term mean monthly streamflow for the period of record at the Souris River above Minot, N. Dak. (site 7; fig. 3; National Oceanic and Atmospheric Administration, 2021; U.S. Geological Survey, 2021). The streamflow in the preceding 8 months (October 2020 through May 2021) was mostly near 0 ft<sup>3</sup>/s at site 1 from minimal Lake Darling releases, except for April 2021, when releases were about 100 ft<sup>3</sup>/s during spring snow melt (fig. 2).

Releases from Lake Darling were increased from about 30 ft<sup>3</sup>/s to more than 100 ft<sup>3</sup>/s from June 14 to July 20 to overcome the loss in streamflow in June 2021 and provide enough flow to J. Clark Salyer Pool further downstream to meet the minimum streamflow requirements needed to be delivered to Manitoba (figs. 1 and 2). During this period of increased releases, streamflow in the reach between sites 1 and 7 increased and a loss was not observed. However, during the period of higher flow, the reach between sites 7 and 22 indicated a loss in daily mean streamflow of about as much as 13 ft<sup>3</sup>/s. Releases were then reduced to about 0 ft<sup>3</sup>/s from July 21 to August 10 to maintain storage in Lake Darling. Daily mean streamflow at sites 1 and 7 decreased to less than 1 ft<sup>3</sup>/s by August 4, and daily mean streamflow at site 22 was reduced to about 4.6 ft<sup>3</sup>/s by August 19 (fig. 2).

Streamflow measurements were made at 22 sites on August 31 and September 1, 2021, to determine where gains and losses occur on the Souris River during low-flow conditions (fig. 1). To make this determination, releases from Lake Darling were increased to about 40 ft<sup>3</sup>/s on August 11 and were held steady with no additional inputs added, such as runoff from rainfall events, through September 2.

Streamflow measurements made on August 31, 2021, did not indicate the same loss in streamflow that was observed at the three streamgages (sites 1, 7, and 22) in June 2021. Measurements made at sites 1, 7, and 22 on August 31 had streamflows of 44.2, 45.9, and 46.8 ft<sup>3</sup>/s, respectively (fig. 4;

#### 4 Streamflow Gain and Loss on the Souris River between Lake Darling and Verendrye, North Dakota

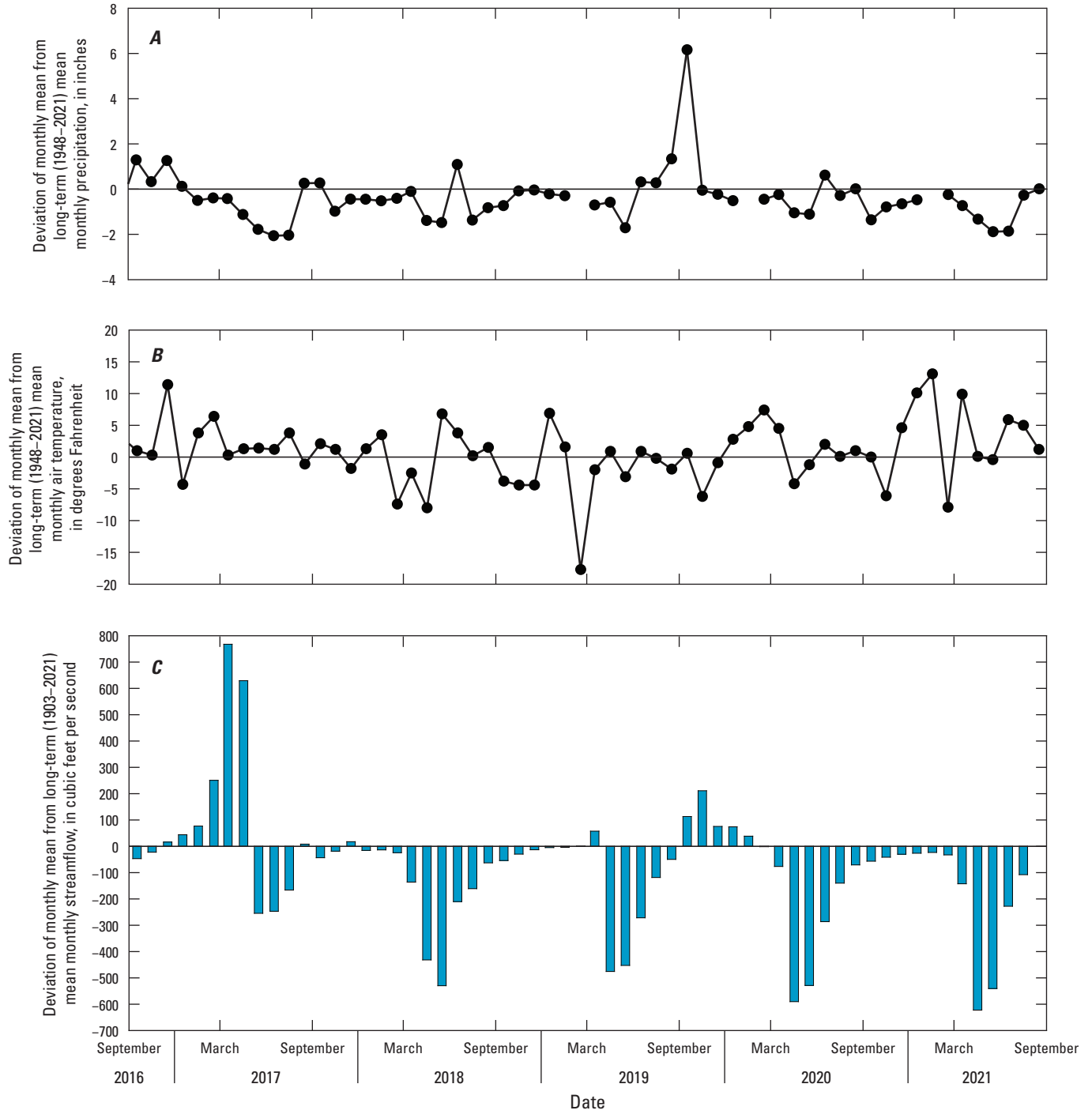


**Figure 2.** Daily mean streamflow for the U.S. Geological Survey streamgages on the Souris River near Foxholm, North Dakota (station 05116000), Souris River above Minot, N. Dak. (station 05117500), and Souris River near Verendrye, N. Dak. (station 05120000), October 1, 2020, through September 30, 2021.

table 1). Streamflow measured at all 22 sites on August 31 and September 1 on the Souris River ranged from 38.4 ft<sup>3</sup>/s (site 9) to 49.8 ft<sup>3</sup>/s (site 12). No inflow was observed from the Des Lacs River to the Souris River near the confluence with the Souris River (site 4; fig. 1). In general, the largest change in streamflow was measured among sites on the Souris River in or near the city of Minot, N. Dak. (figs. 1 and 4; table 1). The largest loss in streamflow between upstream and downstream sites was measured between site 8 (measured on August 31) and site 9 (measured on September 1), with a loss of about 9.5 ft<sup>3</sup>/s. However, the next site downstream, site 10, had nearly the same measured flow as site 8 (fig. 4; table 1). Because of windy conditions, the measurement at site 9 was rated poor, with an uncertainty of greater than plus or minus 8 percent of the measured streamflow, which would be more than 3.1 ft<sup>3</sup>/s (table 1). A streamflow loss of 7.5 ft<sup>3</sup>/s also was measured between sites 12 and 13 (figs. 1 and 4; table 1). The loss had a relative percent difference in streamflow of about 16 percent between measurements. The measurement at site 12 was rated poor and the measurement at site 13 was rated good, indicating an uncertainty of more than plus or minus 13 percent (5 percent plus 8 percent; table 1). At the next site downstream, site 14, the measured streamflow was similar to site 13, verifying the loss between sites 12 and 13 (fig. 4).

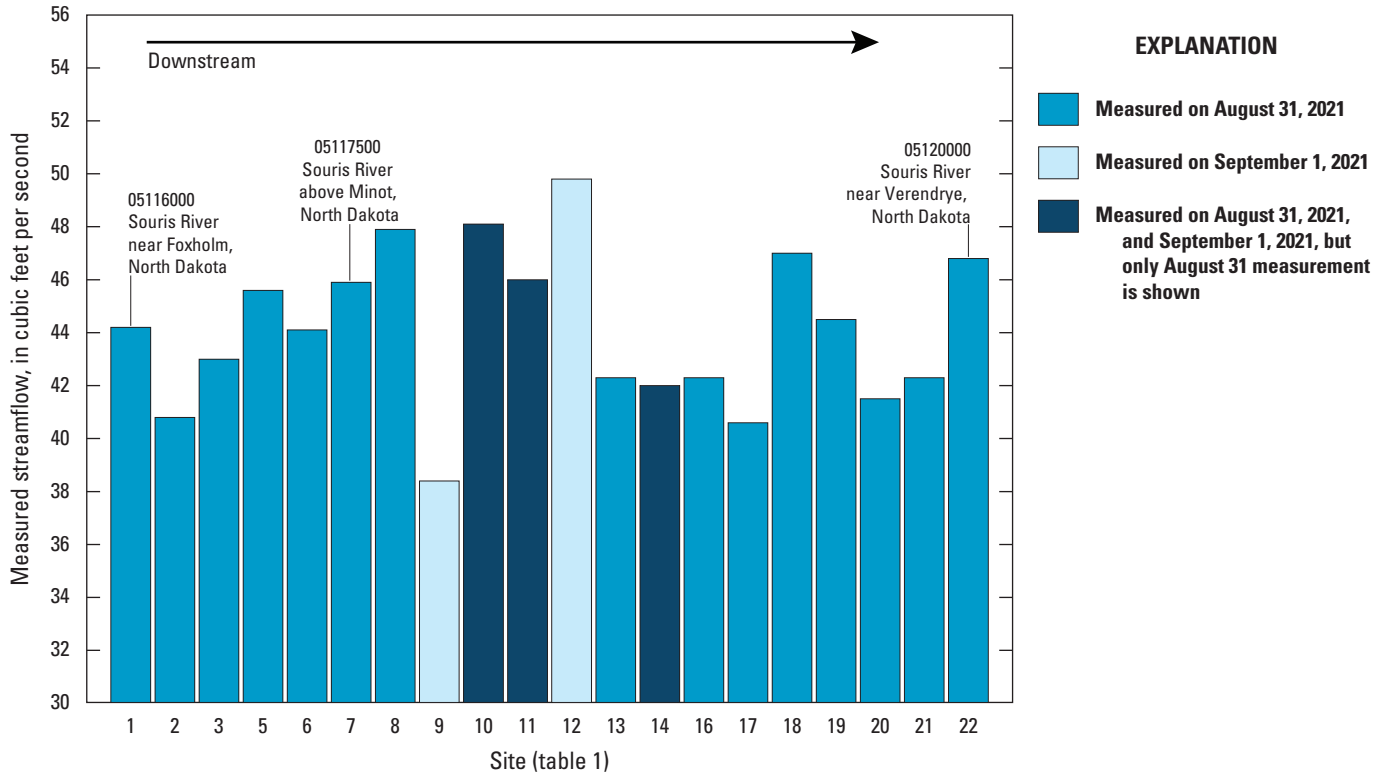
Site 14 also was measured on August 31 and September 1 and had similar values for the two streamflow measurements (table 1). Between sites 14 and 16, inflow to the Souris River from the Minot wastewater treatment plant (site 15) was measured at 1.99 ft<sup>3</sup>/s (fig. 1; table 1). An increase in streamflow of 6.4 ft<sup>3</sup>/s was measured between sites 17 and 18, and an increase of 4.5 ft<sup>3</sup>/s was measured between sites 21 and 22 (fig. 4). Differences in measured streamflow among all other sites were smaller and within the uncertainty of the measurements.

Several reasons are possible for why the loss of streamflow in the reach between sites 1 and 22 in early June 2021 was not observed on August 31 and September 1 when the measurements were made. The increased releases from Lake Darling and several rainfall events in late June to late July produced streamflows greater than 100 ft<sup>3</sup>/s in the reach between sites 1 and 22 (fig. 2). The sustained higher streamflow may have increased the water storage in the banks and streambed material even after the streamflow was reduced near the end of July through August. Also, withdrawals from the Souris River could have been different from June through August. No data were available for permitted or unpermitted withdrawal volumes from the Souris River to determine any differences from June through August 2021.



**Figure 3.** Monthly precipitation and air temperature for Minot, North Dakota (station USW00024013; National Oceanic and Atmospheric Administration, 2021), and monthly streamflow for the U.S. Geological Survey streamgage Souris River above Minot, N. Dak. (station 05117500), September 2016 through September 2021 (U.S. Geological Survey, 2021). *A*, deviation of monthly mean precipitation from long-term mean monthly values (1948–2021); *B*, deviation of monthly mean air temperature from long-term mean monthly values (1948–2021); *C*, deviation of monthly mean streamflow from long-term mean monthly values (1902–2021).

**6 Streamflow Gain and Loss on the Souris River between Lake Darling and Verendrye, North Dakota**



**Figure 4.** Measured streamflow at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota (station 05116000), and Souris River near Verendrye, N. Dak. (station 05120000), August 31 and September 1, 2021.

**Table 1.** Streamflow measurements made at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota (station 05116000), and Souris River near Verendrye, N. Dak. (station 05120000), August 31 and September 1, 2021.

[Calculation of relative percent difference is  $|(x_1 - x_2)/(x_1 + x_2)/2| * 100$ , where  $x_1$  is the downstream measurement and  $x_2$  is the upstream measurement. USGS, U.S. Geological Survey; ft<sup>3</sup>/s, cubic foot per second; N. Dak., North Dakota; --, no data; P, poor; ADCP, acoustic Doppler current profiler; OBS, observed; G, good; ADV, acoustic Doppler velocimeter; F, fair; NW, northwest; SE, southeast; N, north; NE, northeast, SW, southwest]

Map identification number (fig. 1)	USGS station	Site name	Latitude (decimal degrees)	Longitude (decimal degrees)	Measured streamflow (ft <sup>3</sup> /s)	Difference in streamflow (downstream minus upstream) (ft <sup>3</sup> /s)	Relative percent difference in streamflow	Measurement rating <sup>1</sup>	Measurement instrument
August 31, 2021									
1	05116000	Souris River near Foxholm, N. Dak.	48.3722	-101.5050	44.2	--	--	P	ADCP
2	482029101274300	Souris River at river mile 426.2 near Foxholm, N. Dak.	48.3415	-101.4620	40.8	-3.4	8	P	ADCP
3	481245101253500	Souris River at river mile 415.3 near Burlington, N. Dak.	48.2958	-101.4263	43.0	2.2	5	P	ADCP
4	481653101252300	Des Lacs River at Old Settlers Park at Burlington, N. Dak.	48.2813	-101.4231	0	--	--	--	OBS
5	481646101250700	Souris River near confluence of Des Lacs River near Burlington, N. Dak.	48.2796	-101.4186	45.6	2.6	6	G	ADV
6	481517101240100	Souris River at river mile 409 at Minot, N. Dak.	48.2547	-101.4003	44.1	-1.5	3	G	ADCP
7	05117500	Souris River above Minot, N. Dak.	48.2461	-101.3720	45.9	1.8	4	G	ADCP
8	481343101202900	Souris River at Highway 83 Bypass bridge at Minot, N. Dak.	48.2286	-101.3413	47.9	2.0	4	F	ADCP
10	481433101181800	Souris River at 8th Street NW bridge at Minot, N. Dak.	48.2425	-101.3050	48.1	0.2	0	G	ADCP
11	05117600	Souris River at Broadway Bridge at Minot, N. Dak.	48.2381	-101.2958	42.9	-5.2	11	P	ADCP

**Table 1.** Streamflow measurements made at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota (station 05116000), and Souris River near Verendrye, N. Dak. (station 05120000), August 31 and September 1, 2021.—Continued

[Calculation of relative percent difference is  $|(x_1 - x_2)/(x_1 + x_2)/2| * 100$ , where  $x_1$  is the downstream measurement and  $x_2$  is the upstream measurement. USGS, U.S. Geological Survey; ft<sup>3</sup>/s, cubic foot per second; N. Dak., North Dakota; --, no data; P, poor; ADCP, acoustic Doppler current profiler; OBS, observed; G, good; ADV, acoustic Doppler velocimeter; F, fair; NW, northwest; SE, southeast; N, north; NE, northeast, SW, southwest]

Map identification number (fig. 1)	USGS station	Site name	Latitude (decimal degrees)	Longitude (decimal degrees)	Measured streamflow (ft <sup>3</sup> /s)	Difference in streamflow (downstream minus upstream) (ft <sup>3</sup> /s)	Relative percent difference in streamflow	Measurement rating <sup>1</sup>	Measurement instrument
August 31, 2021—Continued									
13	481316101174500	Souris River at river mile 393.8 at Minot, N. Dak.	48.2211	-101.2436	42.3	-0.6	1	G	ADV
14	481148101124800	Souris River at 37th Avenue SE near Minot, N. Dak.	48.1966	-101.2134	39.2	-3.1	8	F	ADV
16	480911101090200	Souris River at Logan, N. Dak.	48.1531	-101.1500	42.3	1.1	3	G	ADCP
17	480542101030200	Souris River at Sawyer, N. Dak.	48.0949	-101.0504	40.6	-1.7	4	F	ADCP
18	480350100554400	Souris River at Velva, N. Dak.	48.0639	-100.9289	47.0	6.4	15	F	ADCP
19	480545100514900	Souris River at 13th Avenue N bridge NE of Velva, N. Dak.	48.0956	-100.8634	44.5	-2.5	5	G	ADCP
20	480651100483400	Souris River at river mile 340.5 near Verendrye, N. Dak.	48.1143	-100.8095	41.5	-3.0	7	G	ADCP
21	480733100450300	Souris River at 49th Street N bridge near Verendrye, N. Dak.	48.1257	-100.7509	42.3	0.8	2	F	ADCP
22	05120000	Souris River near Verendrye, N. Dak.	48.1597	-100.7292	46.8	4.5	10	G	ADV
September 1, 2021									
9	481342101186000	Souris River at 16th Street SW bridge at Minot, N. Dak.	48.2284	-101.3165	38.4	--	--	P	ADCP
10	481433101181800	Souris River at 8th Street NW bridge at Minot, N. Dak.	48.2425	-101.3050	46.1	7.7	18	F	ADCP



**Table 1.** Streamflow measurements made at selected sites on the Souris River between the U.S. Geological Survey streamgages Souris River near Foxholm, North Dakota (station 05116000), and Souris River near Verendrye, N. Dak. (station 05120000), August 31 and September 1, 2021.—Continued

[Calculation of relative percent difference is  $|(x_1 - x_2)/(x_1 + x_2)/2| * 100$ , where  $x_1$  is the downstream measurement and  $x_2$  is the upstream measurement. USGS, U.S. Geological Survey; ft<sup>3</sup>/s, cubic foot per second; N. Dak., North Dakota; --, no data; P, poor; ADCP, acoustic Doppler current profiler; OBS, observed; G, good; ADV, acoustic Doppler velocimeter; F, fair; NW, northwest; SE, southeast; N, north; NE, northeast, SW, southwest]

Map identification number (fig. 1)	USGS station	Site name	Latitude (decimal degrees)	Longitude (decimal degrees)	Measured streamflow (ft <sup>3</sup> /s)	Difference in streamflow (downstream minus upstream) (ft <sup>3</sup> /s)	Relative percent difference in streamflow	Measurement rating <sup>1</sup>	Measurement instrument
September 1, 2021—Continued									
11	05117600	Souris River at Broadway Bridge at Minot, N. Dak.	48.2381	-101.2958	46.0	-2.1	4	F	ADCP
12	481415101165900	Souris River at 7th Street NE Bridge at Minot, N. Dak.	48.2375	-101.2831	49.8	3.8	8	P	ADCP
14	481148101124800	Souris River at 37th Avenue SE near Minot, N. Dak.	48.1966	-101.2134	42.0	-7.8	17	P	ADCP
15	481045101094300	Unnamed tributary downstream from Minot wastewater discharge at Minot, N. Dak.	48.1790	-101.1618	1.99	--	--	G	ADV

<sup>1</sup>Measurements rated excellent have an uncertainty of about 2 percent of the measured streamflow, measurements rated good have an uncertainty of about 5 percent of the measured streamflow, measurements rated fair about 8 percent uncertainty of the measured streamflow, and measurements rated poor have a greater than 8 percent uncertainty (Turnipseed and Sauer, 2010).

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