SALINITY IN SURFACE WATER IN THE RED RIVER OF THE NORTH BASIN, NORTHEASTERN NORTH DAKOTA

By Michael L. Strobel and Norman D. Haffield

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre	4,047	square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
degree Fahrenheit (°F)	[1]	degree Celsius
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.00006309	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton per day	0.9072	megagram per day

[1]Temp °C = (temp °F-32)/1.8.

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.

Microsiemens per centimeter at 25 degrees Celsius (µS/cm) replaces micromhos per centimeter at 25 degrees Celsius used for specific conductance in older reports. The two units are equivalent.

Salinity In Surface Water in the Red River of the North Basin, Northeastern North Dakota

By Michael L. Strobel *and* Norman D. Haffield

ABSTRACT

Saline ground-water discharge from bedrock aquifers collects in wetlands that drain into tributaries of the Red River of the North (Red River). The Turtle, Forest, and Park Rivers are the major contributors of salinity to the Red River. These three rivers drain areas of wetlands affected by ground-water discharge from bedrock and by direct evapotranspiration.

This report describes the effect of tributaries in northeastern North Dakota on the quality of water in the Red River and examines the possible processes that affect salinity in tributaries and wetlands in the area. Streamflow and specific-conductance measurements were made at the mouths of the three tributaries and at streamflow-gaging stations on the Red River at Grand Forks and at Drayton during the fall and winter of 1992-93. During this low-flow period, the three tributaries accounted for about 1.2 percent of the total streamflow in the Red River at Drayton, yet contributed an average of 17 percent (at times up to 43 percent) of the dissolved-solids load.

Long-term streamflow records at Grand Forks and at Drayton show that less than 15 percent of the annual streamflow in the Red River at Drayton occurs during November through February. However, long-term specific-conductance measurements show an increase in dissolved-solids concentrations during this period. In addition, records indicate that there is an average increase in dissolved-solids load in the Red River between Grand Forks and Drayton of 35 percent during November through February. This increase is attributed to inflow from the Turtle, Forest, and Park Rivers.

The salinity in the Turtle, Forest, and Park Rivers may be attributed to natural ground-water discharge and flowing wells, leaching of surface sediments, and contributions from wetlands that have large dissolved-solids concentrations because of evapotranspiration.

INTRODUCTION

The Red River of the North (hereinafter referred to as the Red River) forms the boundary between North Dakota and Minnesota (fig. 1) and is a major source of water for municipal and industrial uses in the region. The Red River flows north through Winnipeg, Manitoba, and, therefore, its water quantity and quality have important international implications. Many groups, such as The International Coalition, the International Joint Commission, the Red River Water Resources Council, and the International Red River Pollution Board, are interested in determining the factors that affect water quality of the Red River and developing future management plans. One of the most significant water-quality concerns is the large levels of salinity in the Red River.

The water quality of a stream is dependent on many factors, including the source and quantity of the streamflow and the types of geology and soils along the path of the stream. Most flow in northern prairie

Figure 1. Location of Red River of the North Basin.

streams is derived from snowmelt and rainfall runoff except during low-flow periods when most streamflow is derived from ground-water discharge. Because ground water generally is more mineralized than snowmelt and rainfall runoff, dissolved-solids concentrations in streams usually are larger during low-flow periods than during high-flow periods.

Purpose and Scope

The purposes of this report are to describe the effects of selected tributaries in northeastern North Dakota on the water quality of the Red River and to examine possible processes that affect salinity in the tributaries and wetlands. This report is a product of a larger 3-year study from 1991 to 1993 to evaluate the effects of upward migration of saline ground water from bedrock aquifers through surficial sediments on the water quality of the Red River. The study is part of the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program. The study area includes all of Grand Forks County and the eastern half of Walsh County (fig. 2). The area is 2,134 mi^2 and is roughly bounded on the west by the margin of the Red River Lake Plain and on the east by the Red River. The area includes parts of the Turtle River, Forest River, and Park River drainage areas.

Background

Field reconnaissance during June and July 1991 included specific-conductance measurements in the Red River and its tributaries in North Dakota and Minnesota. Strobel and Gerla (1992) showed that large dissolved-solids concentrations occur in the Turtle, Forest, and Park Rivers. Dissolved-solids concentrations in these tributaries increase markedly as the tributaries flow through areas of wetlands (fig. 3) and saline soils (fig. 4). The occurrence of these wetlands and saline soils is related to the subcrop of bedrock aquifers beneath glacial and lacustrine sediments. A synoptic measurement of streamflow and specific conductance in the Red River and its tributaries completed in December 1991 during a low-flow period indicated that the three tributaries contributed about 6 percent of the streamflow in the Red River at the international boundary but accounted for more than 30 percent of the dissolved solids (Strobel and Gerla, 1992). Results of these field measurements helped focus this investigation on the area drained by those tributaries.

During the 1992 water year, dissolved-solids concentrations in the Red River at the international boundary ranged from about 257 mg/L during high-flow periods to about 1,020 mg/L during low-flow periods (Harkness and others, 1993). During the same year, dissolved-solids concentrations were in excess of 5,000 mg/L in many of the wetlands in northeastern North Dakota and in tributaries to the Red River. Discharge from these wetlands and tributaries accounts, in part, for the large salinity levels in the Red River at certain times.

The water quality of wetlands in northeastern North Dakota is different from that of most prairie potholes in the upper Midwest. Wetlands in the Red River Basin in northeastern North Dakota have sodium-chloride-type waters, whereas prairie potholes, in general, have magnesium-sulfate-type waters because of local flowpaths in hummocky glacial terrains (Strobel and Gerla, 1993). The distinct water chemistry in wetlands in the Red River Basin is presumed to be related to saline ground-water discharge from bedrock aquifers that subcrop beneath surficial glacial and lacustrine sediments in the basin. Upward vertical gradients in hydraulic head between the bedrock aquifers and the surficial sediments in northeastern North Dakota indicate the potential for upward migration of saline ground water to the land surface. The marked similarity between the water chemistry in the wetlands and the water chemistry in the bedrock aquifers corroborates the hydraulic evidence that the wetlands receive water from ground-water discharge. Therefore, the water quality of wetlands in the Red River Basin and, in turn, the water quality of the Red River probably is affected by saline ground-water discharge.

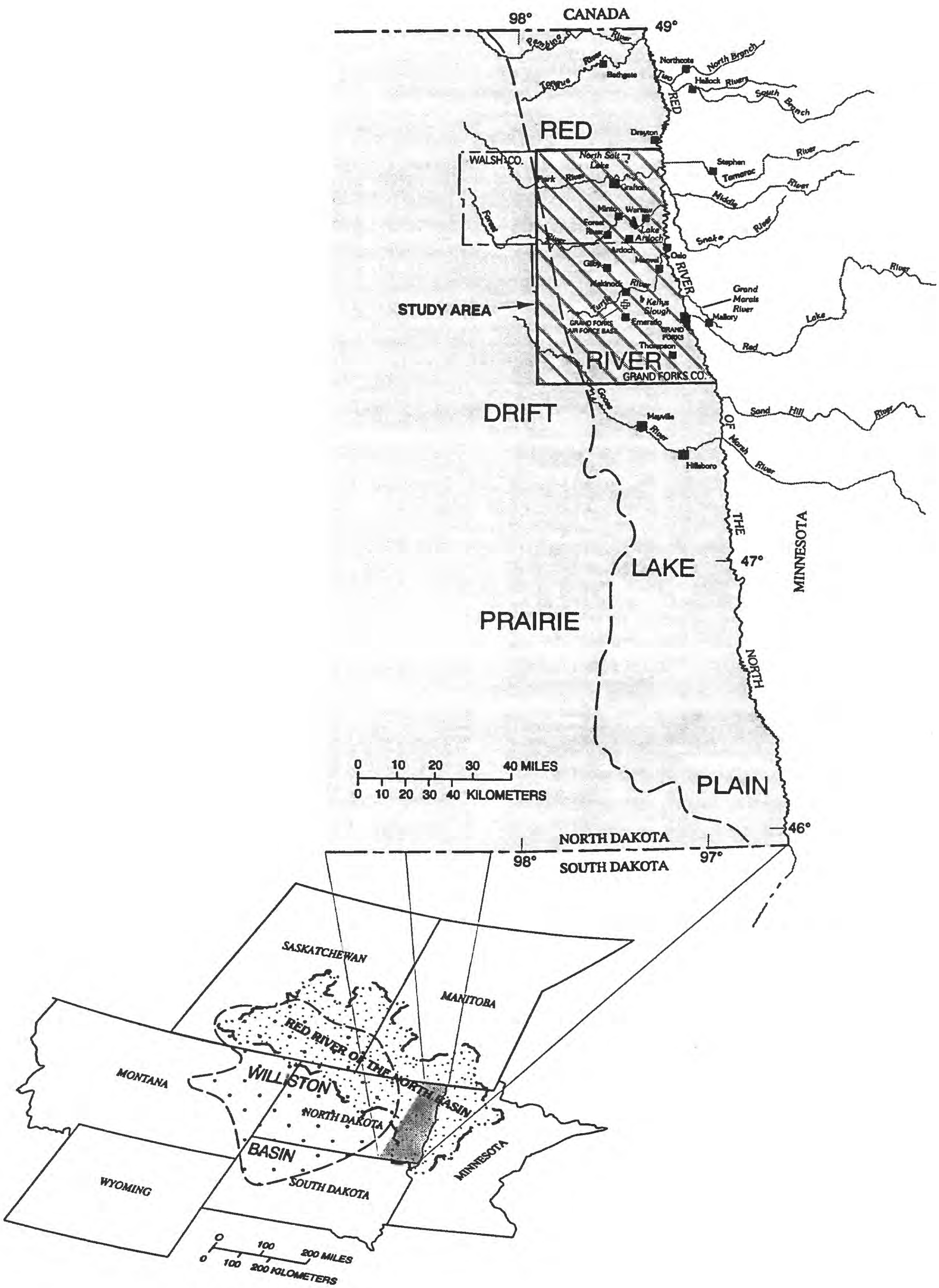

Figure 2. Study area in Grand Forks County and eastern Walsh County, North Dakota.

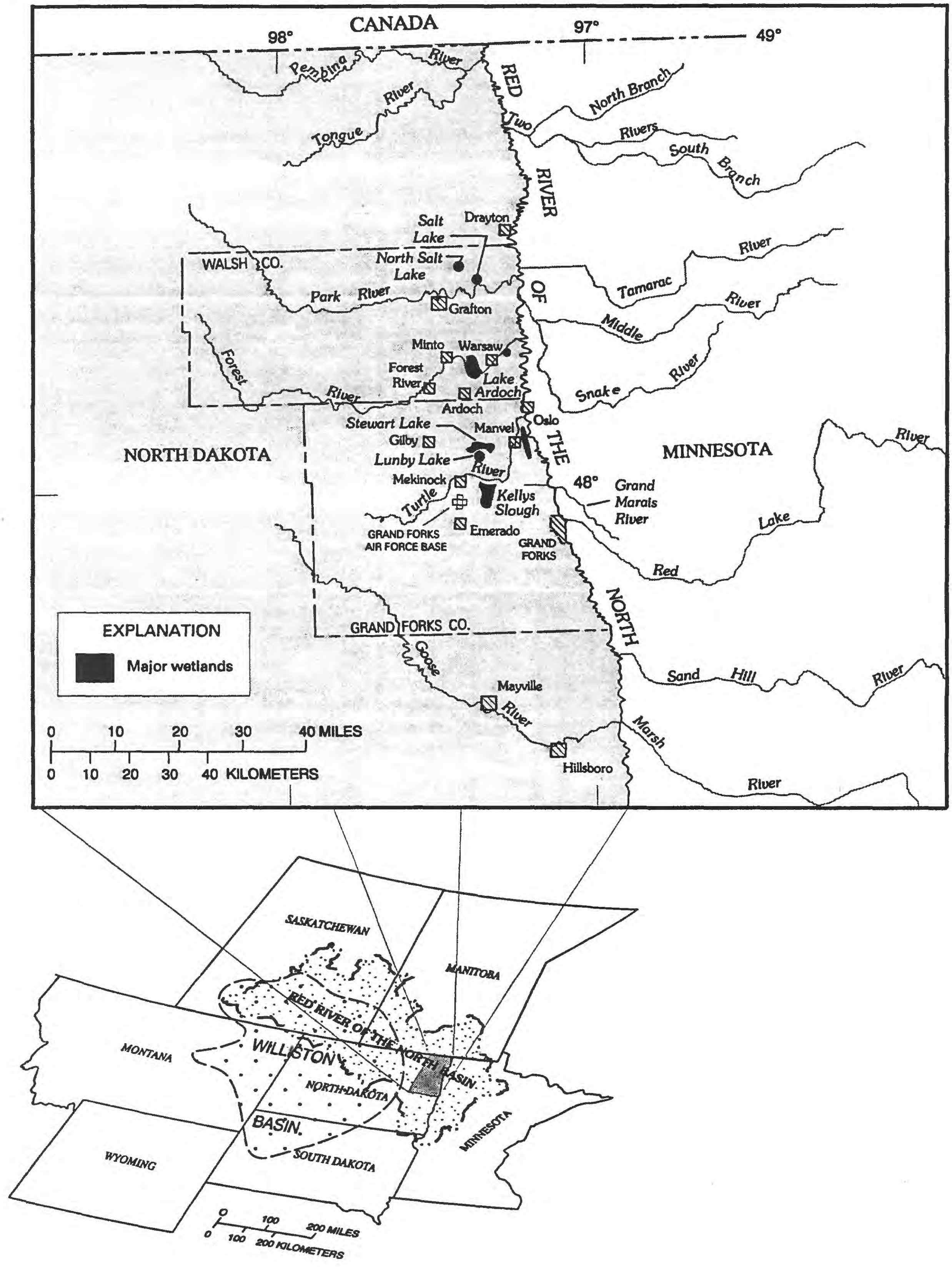

Figure 3. Major wetlands in the central Red River of the North Basin.

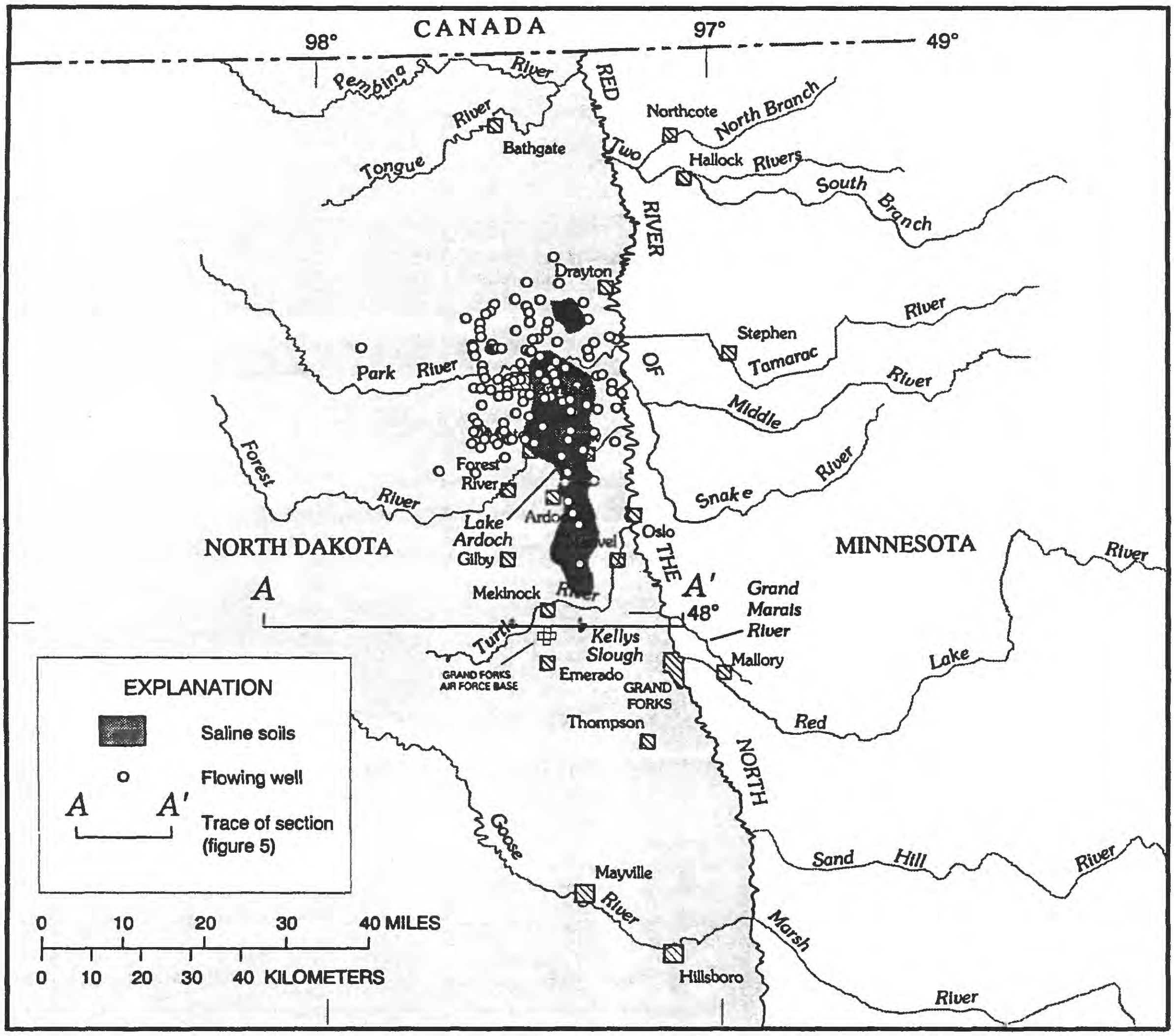

Figure 4. Areas of saline soils and locations of flowing wells in the central Red River of the North Basin. (From Strobel and Gerla, 1992.)

Saline ground-water discharge from bedrock aquifers to the land surface in the Red River Basin generally occurs at specific locations, represented as lakes and wetlands (fig. 3), and its distribution probably is related to heterogeneities in the surficial sediments. However, the presence of large areas of saline soils in northeastern North Dakota (fig. 4) indicates that salinity also reaches the land surface by some other mechanisms--possibly saline ground-water movement over large areas from bedrock sources upward through fine-grained surficial sediments by advection resulting from the large hydraulic gradient, diffusion of salinity from large concentrations in the bedrock aquifers upward through the saturated sediments, or runoff from flowing wells. Tributaries that flow across the Red River Basin and discharge to the Red River transport dissolved ions leached from the soils. These ions then contribute to the salinity levels in the Red River.

Wetlands in the Red River Basin usually consist of shallow bodies of water. Evapotranspiration from these wetlands can cause concentration of dissolved solids in the water. Outflow from the wetlands enters the tributaries to the Red River and causes an increase in salinity levels in the Red River. Therefore, evapotranspiration from the wetlands may affect the water quality of the Red River.

Historical Background

Although flowing wells may have contributed to the occurrence of saline soils and wetlands in the Red River Basin, the problem was present long before the arrival of European-Americans who drilled the first wells in the basin. Native Americans have long made camps along the Park and Forest Rivers. The Assiniboine constructed "parks" (corrals) in which to herd and harvest buffalo along these rivers; thus, the name for the Park River (Lounsberry, 1917). These areas may have been desirable locations because of the natural salt deposits, which were useful for the preservation of meat. In the 1800's, the Metis (mixed European and Native American descendants) also hunted buffalo along these rivers (Robinson, 1966). Alexander Henry, the first European-American trader to settle in the area (1801), noted extremely large numbers of bear, buffalo, deer, beaver, wolves, and other wildlife in the Red River Basin (Lounsberry, 1917). The wildlife possibly were attracted to the area by the salt deposits.

Settlement in the area initially occurred along major rivers. With the coming of the railroad in the 1860's, settlements began expanding into the interior of North Dakota. Land in the Red River Valley was parceled into quarter sections, and no person was allotted more than 480 acres (Upham, 1895). In many areas, the salinity of the soils made agricultural production difficult and crops often were limited to grasses. Drainage ditches constructed throughout the valley drained field runoff and wetland areas and probably increased the amount of salinity transported to the Red River. Many homesteaders installed wells for water supplies, but the deep ground water was too saline for consumption or irrigation. Many of these wells flowed at land surface and either were capped or were abandoned with unrestricted flow, which typically was large. For example, a well drilled at Minto in Walsh County (fig. 2), had a hydraulic head of more than 60 ft above land surface and a flow rate of more than 800 gal/min (Upham, 1895). It is probable that settlement of the Red River Valley caused an increase in salinity levels in the Red River and its tributaries because of the drainage of wetlands and the installation of flowing wells that discharged saline ground water to the land surface.

Previous Investigations

Little information is available on the specific locations of ground-water discharge in the basin. Bedrock aquifers of the Williston Basin, a regional structural feature west of the study area (fig. 2), generally discharge to the Red River Basin. In the central part of the Red River Basin, glacial and lacustrine sediments that have very small hydraulic conductivities overlie bedrock aquifers of Paleozoic and Cretaceous age (fig. 5). Although the flow velocity and rate of discharge generally are small, water from the bedrock aquifers discharges upward through the surficial sediments and reaches the land surface in numerous areas in northeastern North Dakota (Gerla, 1992). Laird (1944) and Downey (1973, 1986) discussed the possibility of ground-water flow through silty zones in surficial sediments that have relatively large hydraulic conductivities. These silty zones act as conduits for the upward flow of ground water.

Strobel (1992) showed that many areas of saline soils and wetlands are not related to textural variations in the surficial sediments but may be caused by diffusion or by very slow saline ground-water advection from Paleozoic and Cretaceous rocks that underlie the glacial and lacustrine sediments. Strobel (1992), Strobel and Gerla (1992), and Strobel and others (1994) suggested that flowing wells may be responsible for some of the saline ground-water discharge to the land surface. In general, whatever the mechanism, areas of saline ground-water discharge are represented as areas of saline soils (fig. 4) and occur mainly in Grand Forks County and eastern Walsh County.

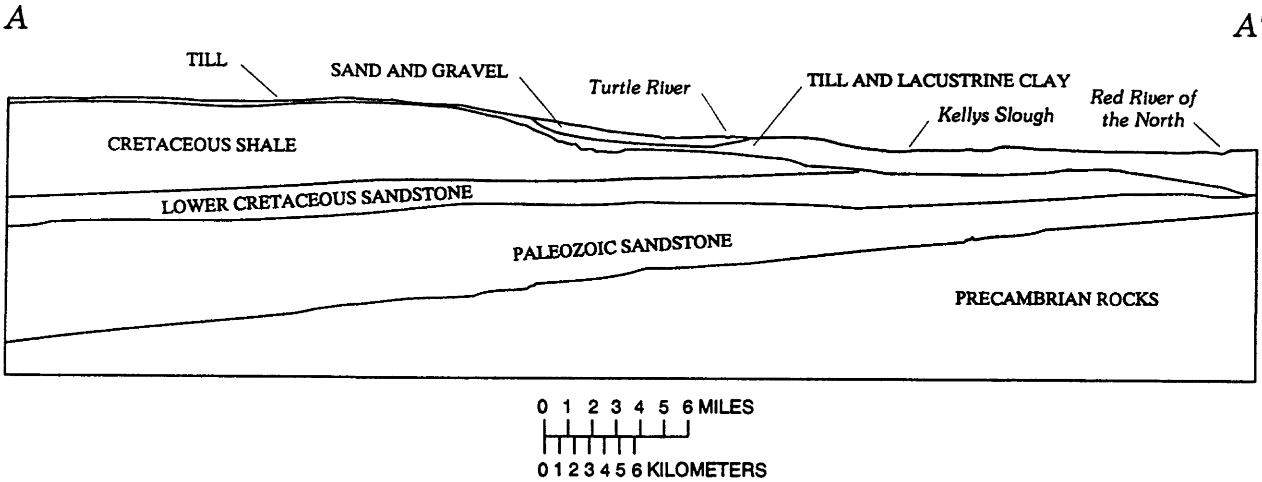

Figure 5. Geologic section in the Red River of the North Basin near Grand Forks, North Dakota. (From Strobel and Gerla, 1992.)

In 1976, the U.S. Environmental Protection Agency completed a study of chloride concentrations in the Red River (U.S. Environmental Protection Agency, 1977). As indicated in the study, outflow from Lake Ardoch, on the Forest River (fig. 4), contributes to the large chloride concentrations in the Red River during low-flow periods. The chloride concentration in Lake Ardoch can exceed 6,000 mg/L.

Study Methods

Salinity in streams may be estimated by the use of specific-conductance measurements. Specific conductance is used to estimate the quantity of dissolved solids in water. The relation between specific conductance and dissolved-solids concentration varies for different streamflow conditions, but, in general, the specific conductance, in microsiemens per centimeter at 25 degrees Celsius, ranges from 1.3 to 1.8 times the dissolved-solids concentration, in milligrams per liter (Hem, 1985). A value of 1.6 was used in this report to convert specific conductance to dissolved-solids concentration.

The effect of streamflow contributions from the Turtle, Forest, and Park Rivers on water quality of the Red River was examined in detail. During the fall and winter of 1992-93, streamflow and specific-conductance measurements were made at the mouths of the three tributaries and at streamflow-gaging stations on the Red River at Grand Forks and at Drayton. The measurements on the tributaries and at Drayton were made weekly, weather permitting, and measurements at Grand Forks were made about every 6 weeks. Flow was continuous in all four rivers except for the Park River, which had no measurable streamflow in late January and early February. The gaging stations on the Red River at Grand Forks and at Drayton have continuous stage recorders, so mean daily streamflow was computed for both sites based on stage-discharge relations. The specific conductance was measured from periodic grab samples at each site. Missing data were estimated by interpolation of streamflow and specific-conductance data.

Long-term streamflow records and dissolved-solids loads were examined to better evaluate the effect of the three tributaries on the Red River. Streamflow records for the Red River at Grand Forks are continuous since 1882. Streamflow records for the Red River at Drayton are continuous since 1942. Since 1970, specific-conductance measurements have been made at both stations whenever discharge measurements were obtained or about once every month. This long-term data provided the information so that trends in streamflow and water quality could be examined.

EFFECTS OF TRIBUTARIES ON SALINITY IN THE RED RIVER

Streamflow in the Turtle, Forest, and Park Rivers generally decreased during the fall and winter of 1992-93 although some increase in flow occurred in the Turtle and Forest Rivers during late January and early February. Streamflow in the Red River ranged from 750 to 1,000 ft^3/s at Grand Forks and 560 to 950 ft^3/s at Drayton. During the data-collection period, the combined streamflow of the three tributaries accounted for only about 1.2 percent of the streamflow in the Red River at Drayton.

The dissolved-solids loads in the Turtle, Forest, and Park Rivers fluctuated with changes in streamflow and generally decreased during the data-collection period (table 1). An exception was the dissolved-solids load in the Forest River (and in the Turtle River to a lesser extent) in the latter part of the period. The dissolved-solids load in the Red River at Drayton also fluctuated with changes in streamflow. The proportion of dissolved-solids load in the Red River at Drayton that was contributed by the three tributaries during the study period ranged from 5 to 43 percent and averaged 17 percent. As streamflow contributions from the tributaries decreased, the effect on water quality in the Red River also decreased.

Long-term streamflow records and dissolved-solids loads were examined to better evaluate the effect of the three tributaries on the Red River. Streamflow hydrographs for the Red River at Grand Forks and at Drayton indicate that low flow occurs during late fall and winter. More specifically, on the basis of long-term streamflow records, less than 15 percent of the annual streamflow in the Red River at Drayton occurs during November through February. Streamflow in the Red River during this period is relatively uniform, and inflow from tributaries typically is small. In addition, streamflow comparisons between the Grand Forks and Drayton gaging stations indicate that direct base flow to the Red River is a minor contributor to the total flow. Evapotranspiration during November through February is at a minimum because the Red River normally is ice covered and vegetation in and adjacent to the river is dormant. Mean monthly streamflow for the Red River at Grand Forks and at Drayton for 1970-93 is shown in figure 6.

Mean monthly specific conductance for the Red River at Grand Forks and at Drayton for 1970-93 also is shown in figure 6. Specific-conductance data indicate that dissolved-solids concentrations increase during low-flow periods and then decrease as streamflow increases with spring snowmelt and rainfall runoff. Maximum dissolved-solids concentrations occur during low-flow periods.

The water quality of the Red River at Grand Forks is distinctly different from the water quality of the Red River at Drayton. The average specific conductance for the Red River at Grand Forks for November through February for 1970-93 was about 628 μS/cm; the average for the Red River at Drayton was about 817 μS/cm. Converting specific conductance to dissolved-solids concentration indicates an average dissolved-solids concentration of about 393 mg/L for the Red River at Grand Forks and about 511 mg/L for the Red River at Drayton, an average increase of 118 mg/L between the two gaging stations. Further converting these data to total loads for the November through February period (using mean monthly streamflows for 1970-93) results in an average dissolved-solids load of about 55 million tons for the Red River at Grand Forks and about 74 million tons for the Red River at Drayton, an increase of about 35 percent between the two gaging stations. Therefore, a major contribution to the salinity in the Red River occurs between Grand Forks and Drayton and is attributed to inflow from the Turtle, Forest, and Park Rivers.

PROCESSES THAT AFFECT SALINITY IN SURFACE WATER

Postulation of the processes that affect salinity in the Turtle, Forest, and Park Rivers is a complex issue. Saline ground water may be discharged at specific locations because of textural variations in the

Table 1. Estimate of average streamflow and dissolved-solids load by week for November 22, 1992, through February 6, 1993, for the Red River of the North at Grand Forks, Red River of the North at Drayton, and major tributaries

Location	11/22/92 through 11/28/92	11/29/92 through 12/05/92	12/06/92 through 12/12/92	12/13/92 through 12/19/92	12/20/92 through 12/26/92	12/27/92 through 1/02/93	1/03/93 through 1/09/93	1/10/93 through 1/16/93	1/17/93 through 1/23/93	1/24/93 through 1/30/93	1/31/93 through 2/06/93	Average for period
	Streamflow, in cubic feet per second											
Red River at Grand Forks	890	840	850	900	860	840	750	780	790	880	1,000	850
Turtle River	9.9	[1]8.0	7.0	5.7	5.5	3.9	2.6	3.0	3.5	[1]3.7	[1]3.8	5.1
Forest River	3.9	4.9	4.5	3.1	3.2	1.7	.40	.30	2.6	5.5	5.3	3.2
Park River	6.2	[1]3.7	2.1	2.1	1.4	.80	.25	.10	.03	0	0	1.5
Total	20.0	16.6	13.6	10.9	10.1	6.4	3.2	3.4	6.13	9.2	9.1	9.9
Red River at Drayton	920	560	810	950	880	860	860	770	830	850	860	830
Total streamflow in tributaries as percent of streamflow in Red River at Drayton	2.2	3.0	1.7	1.1	1.1	.7	.4	.4	.7	1.1	1.1	1.2
	Dissolved-solids load, in tons per day											
Red River at Grand Forks	910	830	810	850	810	760	680	710	720	810	940	800
Turtle River	113	[1]86	78	67	54	31	16	18	22	[1]23	[1]23	48
Forest River	94	130	122	87	83	47	12	9.0	78	155	73	81
Park River	200	[1]144	95	108	64	47	17	12	2.0	0	0	63
Total	407	360	295	262	201	125	45	39	102	178	96	192
Red River at Drayton	[1]1,370	[1]830	[1]1,190	[1]1,400	1,250	1,130	950	810	1,060	[1]1,100	[1]1,110	1,110
Total dissolved-solids load in tributaries as percent of dissolved-solids load in Red River at Drayton	30	43	25	19	16	11	5	5	10	16	9	17

[1]Estimated by interpolation of streamflow and (or) specific-conductance data.

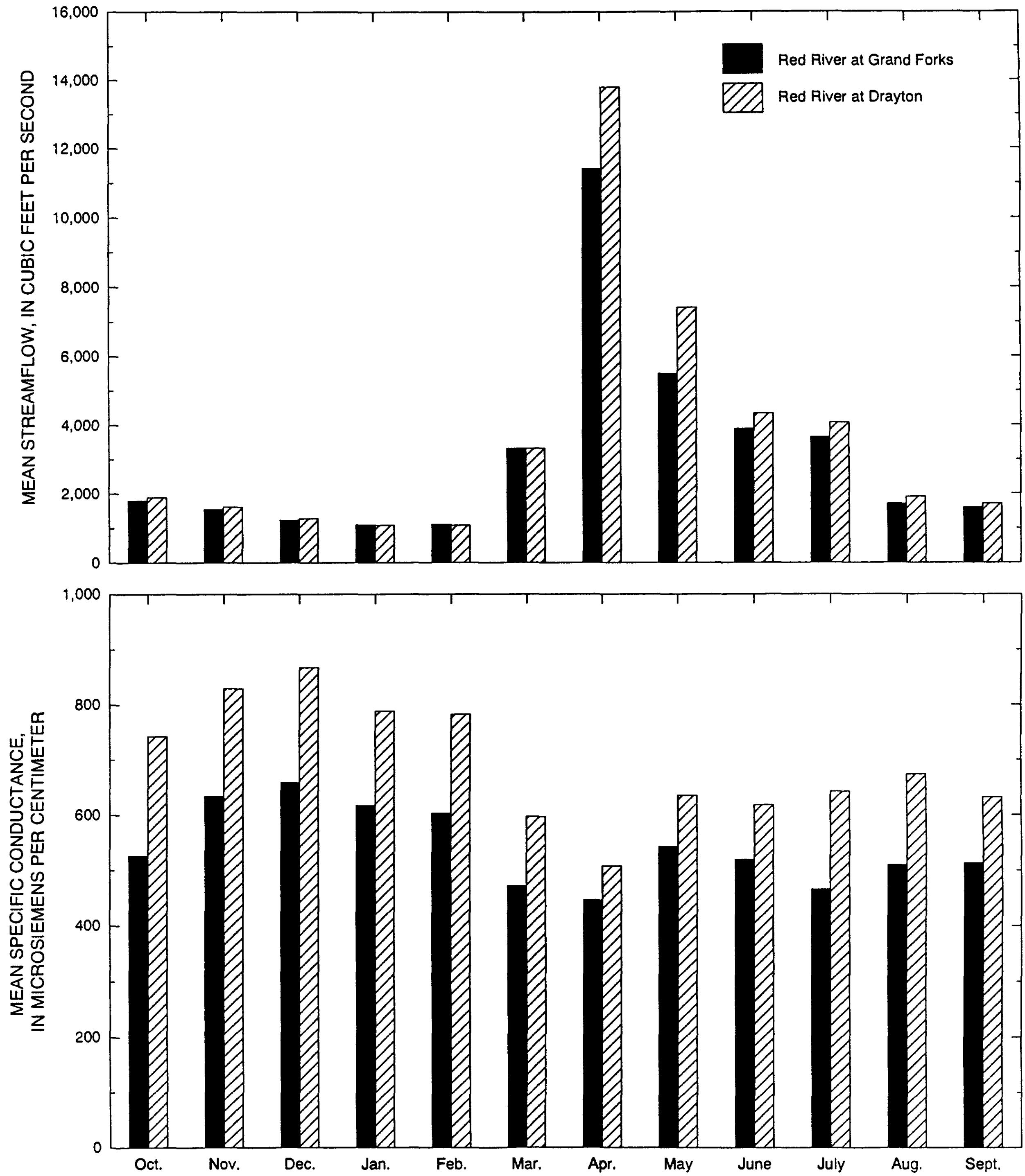

Figure 6. Mean monthly streamflow and mean monthly specific conductance for the Red River of the North at Grand Forks and at Drayton, North Dakota, 1970-93.

surficial sediments in the valley. Field data (Strobel, 1992) indicate that salinity levels in the tributaries increase as the tributaries flow through areas of wetlands and saline soils. Salinity in the tributaries may be attributed to (1) direct saline ground-water discharge to the land surface by natural processes and flowing wells (Strobel, 1992); (2) leaching of surficial sediments in the valley by natural weathering; and (3) periodic saline-water contributions from wetlands that have large dissolved-solids concentrations because of evapotranspiration (outflow from the wetlands to the tributaries occurs during snowmelt and rainfall-runoff events and by releases of water from wetlands that have control structures). The first two factors are difficult to quantify, but the third has been examined in earlier investigations. As previously mentioned, a U.S. Environmental Protection Agency study of chloride concentrations in the Red River indicated that outflow from Lake Ardoch, which can have chloride concentrations that exceed 6,000 mg/L, contributed to increased chloride concentrations in the Red River. Many of the resultant chloride concentrations in the Red River were 100 to 200 mg/L (U.S. Environmental Protection Agency, 1977), which is above the North Dakota State Standard for chloride of 100 mg/L for class 1 streams (North Dakota State Department of Health and Consolidated Laboratories, 1991). Following the U.S. Environmental Protection Agency study, human-controlled releases from Lake Ardoch reportedly ceased.

The origin of wetlands in the Red River Basin and the source of saline water in the wetlands were examined by Strobel and Gerla (1993). They stated that the wetlands occur because of three processes that are related to textural variations in surficial sediments, topographic depressions, and flowing wells. Coarse-grained glacial and lacustrine sediments in certain locations in the valley may allow increased vertical flow of saline ground water. The occurrence of Lake Ardoch, Salt Lake, and Kellys Slough has been attributed to these coarse-grained sediments (Downey, 1986; Strobel, 1992).

Wetlands may develop in depressions on the surface of lacustrine sediments. These depressions may result from abandoned stream channels, wind erosion, and winnowing of fine sediments by the upward flow of ground water as well as from other natural causes. Water from direct precipitation, surface runoff, and ground-water discharge collects in the depressions. Evapotranspiration from the lakes and wetlands causes an increase in dissolved-solids concentrations, which may exceed 20,000 mg/L (Strobel and Gerla, 1993).

Flowing wells may be responsible for some saline ground-water discharge to the land surface in the study area. In a preliminary inventory of flowing wells in Grand Forks and Walsh Counties during 1992-93 (Strobel and others, 1994), discharge from 47 flowing wells ranged from a slight seep to 14 gal/min and specific-conductance values averaged about 8,000 µS/cm. Some specific-conductance values exceeded 20,000 µS/cm. About 24 percent of flowing wells found during the study were not listed in existing data bases, indicating that flowing wells may be more numerous than previously realized. Many flowing wells occur in wetland areas. Because it is unlikely that the wells were originally drilled in the wetlands and marsh areas, it is possible that the wetlands resulted from unrestricted flow from these wells.

The Turtle, Forest, and Park Rivers are major sources of salinity in the Red River. It is unknown if the contribution of salinity from these tributaries can be limited or controlled. Wetlands retain some of the surface water in the area and offer some dilution of saline waters by precipitation runoff and snowmelt. Regulation of flow from the larger wetlands may help reduce salinity input to the Red River. If flow from wetlands along the Turtle, Forest, and Park Rivers were released mostly during periods of high streamflow, concentrations of dissolved solids during periods of low flow in the three tributaries would decrease. If the discharge from flowing wells is restricted, some decrease in surface-water salinity would be expected to occur. However, a subsequent increase in hydraulic head in bedrock aquifers that underlie the region may result in an increase in upward flow through the surficial sediments. All of these possibilities may merit further examination before developing management plans for improving quality of surface water in the Red River Basin.

SUMMARY

The water quality in the Red River is important for municipal and industrial uses in North Dakota and Minnesota, as well as the international implications between the United States and Canada. Most of the streamflow is derived from snowmelt and rainfall runoff except during low-flow periods when most streamflow is derived from ground-water discharge to tributaries to the Red River. The Turtle, Forest, and Park Rivers, which are tributaries to the Red River, contain large dissolved-solids concentrations. The dissolved-solids concentrations in these tributaries increase markedly as the tributaries flow through areas of wetlands and saline soils. The occurrence of these wetlands and saline soils is related to the subcrop of bedrock aquifers beneath glacial and lacustrine sediments. The water chemistry of the wetlands is similar to the water in the bedrock aquifers, which corroborates the hydraulic evidence that the wetlands receive water from ground-water discharge. The large dissolved-solids concentrations in the wetlands mainly is attributed to ground-water discharge; however, evapotranspiration from the wetlands also contributes to the concentration of dissolved solids in the water.

The Red River Basin, especially the areas of the Turtle, Forest, and Park Rivers, has historically been an area of large concentrations of wildlife. Animals possibly were attracted to the area by the natural salt deposits. Settlement to the area was hampered by saline soils limiting agricultural production. In addition, drainage of wetlands and drilling of flowing wells may have increased the amount of salinity in the Red River.

The effect of streamflow contributions from the Turtle, Forest, and Park Rivers on water quality of the Red River was examined during the fall and winter of 1992-93. Streamflow and specific-conductance measurements were made at the mouths of the three tributaries and at streamflow-gaging stations on the Red River at Grand Forks and at Drayton. During the data-collection period, the combined streamflow of the three tributaries accounted for only about 1.2 percent of the streamflow in the Red River at Drayton. However, the dissolved-solids load in the Red River at Drayton that was contributed by the three tributaries during the study period ranged from 5 to 43 percent and averaged about 17 percent.

Long-term streamflow records at Grand Forks and at Drayton were examined to evaluate the effect of the three tributaries on the Red River. Less than 15 percent of the annual streamflow in the Red River at Drayton occurs during November through February. Streamflow in the Red River during this period is relatively uniform; inflow from tributaries is small, base-flow contribution is minor, and evapotranspiration is at a minimum.

Long-term specific-conductance measurements for the Red River at Grand Forks and at Drayton indicate that dissolved-solids concentrations increase during low-flow periods. The average specific conductance for the Red River at Grand Forks for November through February for 1970-93 was about 628 microsiemens per centimeter at 25 degrees Celsius; the average for the Red River at Drayton was about 817 microsiemens per centimeter at 25 degrees Celsius. These values convert to an average dissolved-solids concentration of about 393 milligrams per liter for the Red River at Grand Forks and about 511 milligrams per liter for the Red River at Drayton, an average increase of 188 milligrams per liter between the two stations. Further converting these data to total loads results in an average increase in dissolved-solids load between the two stations of 35 percent. Therefore, a major contribution to the salinity in the Red River is attributed to inflow from the Turtle, Forest, and Park Rivers.

Salinity in the Turtle, Forest, and Park Rivers may be attributed to (1) direct saline ground-water discharge to the land surface by natural processes and flowing wells, (2) leaching of surficial sediments in the valley by natural weathering, and (3) periodic saline-water contributions from wetlands affected mainly by evapotranspiration. Although these processes have been addressed in other studies, it is difficult to quantitatively assess the contribution from any specific process to the overall salinity in the tributaries.

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