Water Quality in the Red River of the North Basin

Minnesota, North Dakota, and South Dakota, 1992–95

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

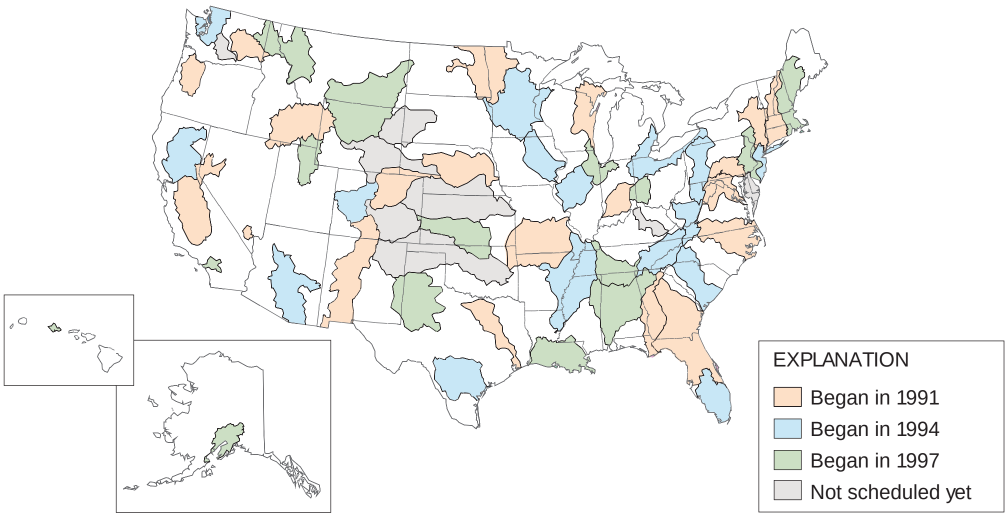
Circular 1169

Water Quality in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1992–95

By J.D. Stoner, D.L. Lorenz, R.M. Goldstein, M.E. Brigham, *and* T.K. Cowdery

U.S. GEOLOGICAL SURVEY CIRCULAR 1169

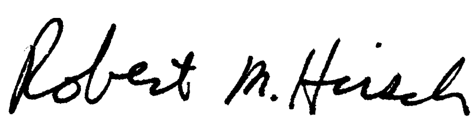
CONTENTS



Knowledge of the quality of the Nation's streams and aquifers is important because of the implications to human and aquatic health and because of the significant costs associated with decisions involving land and water management, conservation, and regulation. In 1991, the U.S. Congress appropriated funds for the U.S. Geological Survey (USGS) to begin the National Water-Quality Assessment (NAWQA) Program to help meet the continuing need for sound, scientific information on the areal extent of the water-quality problems, how these problems are changing with time, and an understanding of the effects of human actions and natural factors on water-quality conditions.

The NAWQA Program is assessing the water-quality conditions of more than 50 of the Nation's largest river basins and aquifers, known as Study Units. Collectively, these Study Units cover about one-half of the United States and include sources of drinking water used by about 70 percent of the U.S. population. Comprehensive assessments of about one-third of the Study Units are ongoing at a given time. Each Study Unit is scheduled to be revisited every decade to evaluate changes in water-quality conditions. NAWQA assessments rely heavily on existing information collected by the USGS and many other agencies as well as the use of nationally consistent study designs and methods of sampling and analysis. Such consistency simultaneously provides information about the status and trends in water-quality conditions in a particular stream or aquifer and, more importantly, provides the basis to make comparisons among watersheds and improve our understanding of the factors that affect water-quality conditions regionally and nationally.

This report is intended to summarize major findings that emerged between 1992 and 1995 from the water-quality assessment of the Red River of the North Basin Study Unit and to relate these findings to water-quality issues of regional and national concern. The information is primarily intended for those who are involved in water-resource management. Indeed, this report addresses many of the concerns raised by regulators, water-utility managers, industry representatives, and other scientists, engineers, public officials, and members of stakeholder groups who provided advice and input to the USGS during this NAWQA Study-Unit investigation. Yet, the information contained here may also interest those who simply wish to know more about the quality of water in the rivers and aquifers in the area where they live.



Robert M. Hirsch, Chief Hydrologist

As a representative of a Canadian natural resources agency, I feel that the extensive knowledge generated by the NAWQA study of the Red River on key environmental issues and underlying processes has given Canadian stakeholders a better understanding of transboundary issues and will contribute significantly to the management of the entire watershed.
Dr. John Wood, Red River NAWQA liaison committee member for Environment Canada, Regina, Saskatchewan

Major Finding	Implication
(A) Background Water Quality.	
Stream quality and basic water quality (as defined by concentrations of major ions) in surficial aquifers are not uniform in the Red River of the North Basin Study Unit (fig. 1). The differences in water quality generally can be related to differences in geology, soils, and hydrology in four subregions in the basin. Saline seeps from deep ground-water sources affect streams in the northwestern portion of the Study Unit during times of extremely low streamflow.	***Water in the Red River of the North Basin, when unaffected by human activities, generally is safe to drink according to U.S. Environmental Protection Agency (USEPA) standards for dissolved solids, major ions, and radionuclides. Natural differences in water quality are important factors for water and land management. [See pages 6–7.]***
(B) Agriculture and Water Quality.	
Pesticide concentrations were mostly related to factors such as chemical persistence and rate of water movement over and through agricultural soils. In this largely agricultural area, the most heavily applied pesticides, which included the herbicides 2,4-D, MCPA, bromoxynil, and trifluralin, were not always the most frequently detected in streams and shallow aquifers. Atrazine, applied at about 7 percent of the rate of 2,4-D, was detected in streams throughout the basin and shallow ground water beneath cropland. The presence of the banned insecticide DDT and some of its breakdown products in stream-bottom sediments, fish tissues, and in some ground water illustrates the persistence of some pesticides.	***Pesticides detected in streams and shallow ground water did not exceed any drinking-water standards and, except for a single concentration of the herbicide triallate, were not acutely toxic to aquatic life based on current standards. USEPA has established drinking-water standards for 6 individual pesticides out of the 43 detected in the basin. The health effects of other pesticides or combinations of pesticides was not assessed. Some insecticides and most fungicides applied to specialty crops in this basin were not analyzed in this study. Pesticide persistence and its dependence on soil characteristics and hydrologic conditions suggest the importance of considering soil, geology, and hydrology in developing and implementing land-management plans. [See pages 8–9.]***
Streams draining areas containing the largest percentage of cropland (central and southern parts of the Red River of the North Basin Study Unit) had the highest concentrations of nutrients (dissolved phosphorus, nitrate, and organic nitrogen).	***Although the nutrient concentrations were relatively low, agricultural activity has increased the concentration and load of nutrients [see pages 10–11] potentially degrading stream quality and increasing eutrophication of lakes and reservoirs. [See page 12.]***
Nitrate concentrations generally were low in shallow ground water except in some surficial aquifers beneath cropland, where concentrations exceeded the USEPA 10 mg/L drinking-water standard in 27, 0, and 8 percent of the samples from the western, central, and southeastern parts of the Study Unit, respectively. Nitrate and pesticide concentrations were well below drinking-water standards in ground water deeper than these aquifers, particularly buried aquifers naturally protected by overlying sediments.	***Ground water most commonly used for domestic and public water supplies in the basin was safe to drink according to USEPA standards for nitrate and pesticides. Detectable concentrations of nutrients and pesticides that have reached ground water indicate the potential for further contamination over time. Shallow ground water beneath sandy soils is particularly vulnerable to contamination, and this study provided a perspective on how decades of agricultural activity affects the current variability of ground-water quality. [See pages 8–11.]***
Fish communities were affected more by differences in natural environmental factors (some of which are affected by land use) than by differences in the concentrations of nutrients and pesticides in streams in agricultural areas.	***More work would be useful to better assess the effects of land use, nutrients, and pesticides on the aquatic ecosystem. [See page 11.]***

Agriculture is the dominant land use in the Red River of the North Basin Study Unit.

Major Finding	Implication

(C) Red River Water Quality and Nonagricultural Sources of Contamination.

Wastewater from urban areas along the Red River of the North has a minimal effect on the river's quality. The median concentration of ammonia, commonly associated with wastewater, was not higher in the river than in the tributaries, but ammonia concentration was slightly higher in the river downstream from the Fargo-Moorhead area. Compared to historical data for the river, concentrations of ammonia have decreased and nitrate have increased slightly downstream from the Fargo-Moorhead area. These trends likely reflect improved aeration of wastewater effluent over time.

Fargo, North Dakota and Moorhead, Minnesota, the largest urban area in the basin, moderately affected Red River of the North water quality during flow conditions observed from 1993 to 1995. Ammonia concentrations were elevated at the point of discharge but were diluted by the river and tributary flows, based on measurements 78 miles downstream at Halstad, Minnesota. This dilution effect also is apparent where industries discharge ammonia to the main stem. [See page 12.]

(D) Effects of other Nonpoint-Source Toxic Compounds on Water Quality.

Mercury, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) (potentially toxic chemicals that are associated with modern industrial sources) were widely detected in Red River of the North Basin Study Unit fish and (or) stream sediments.

Mercury and PCB concentrations in fish tissue were below Federal standards for fish consumption, but some of the highest concentrations were at moderate levels based on Minnesota fish-consumption advisories. PAHs were detected in stream sediments at some locations at levels thought to adversely affect aquatic life. [See page 13.]

Volatile organic compounds (VOCs), sampled in selected shallow aquifers and in the Red River of the North under ice conditions, were detected infrequently and at concentrations well below drinking-water standards.

VOC's, which can enter water from the use of petroleum products and industrial solvents, were rarely detected in ground water beneath agricultural areas or in the Red River of the North. [See pages 10 and 13.]

(E) Sediment in Streams.

High suspended-sediment concentrations characterize streams that flow through the heavily cropped central part of the basin. The highest sediment concentrations coincided with high stream gradient, high streamflows, and erodible stream channels, such as were characteristic of the Pembina River, a tributary to the Red River of the North (fig. 2).

Land-use practices that do not abate rapid runoff of water can increase suspended sediment in streams, thereby reducing water clarity and ecological integrity. Suspended sediment in streams can settle in reservoirs, which could require costly maintenance to restore storage capacity. Sediment delivery to streams may be an important factor for managing nutrient inputs to, and transport in, some streams. [See pages 14–15.]

(F) Importance of Variations in Water Quality.

The highest measured concentrations of herbicides commonly were detected during the first runoff events after application. The herbicide triallate (applied mostly during autumn) and nutrients were transported to streams during spring-snowmelt runoff. Relatively minor differences in the timing of recharge, agricultural practices, and geology can cause significant differences in magnitudes and fluctuations of nitrate concentrations in shallow ground water. Seasonal variation in flow affects available habitat and fish community composition (an indicator of stream quality).

Water-quality criteria and indicators used for monitoring and overall management of contamination sources for water resources in this basin could be enhanced by considering the water-quality effects of seasonal and hydrologic variability. [See pages 16–17.]

Widespread flooding, such as occurred during the spring of 1997, can affect stream quality.

The Red River of the North (hereinafter Red River) Basin was selected as a Study Unit under the NAWQA Program because:

- The basin represents an important hydrologic region where water is a valuable resource for the region's economy.
- The quality of the Red River is of international concern.
- The basin represents an economically valuable agricultural area.
- The northern location is useful for a complete understanding of the Nation's water quality.

The Red River, located near the geographic center of the North American continent, flows northward and drains an area that is largely a glacial lake plain. The Red River Basin Study Unit (figs. 1 and 2) includes the surface drainage to the Red River and Roseau River within the United States. The Devils Lake Basin is not part of the Study Unit.

To assess the water quality in the basin, the Study Unit was divided into four subregions (fig. 2) that represent reasonably homogeneous environmental conditions of climate, topography, geology, soils, and land use and land cover. These environmental conditions can affect the amounts and concentrations of chemicals, sediment, and biota in water.

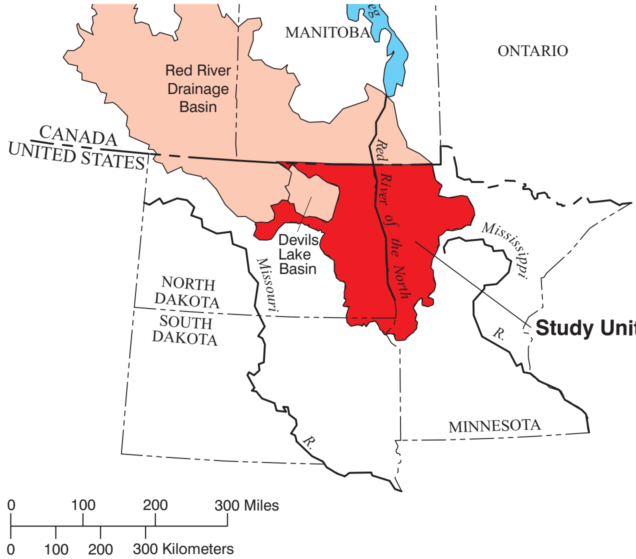


Figure 1. The Red River of the North Basin Study Unit is located in Minnesota, North Dakota, and South Dakota. The Red River of the North flows northward into Canada.

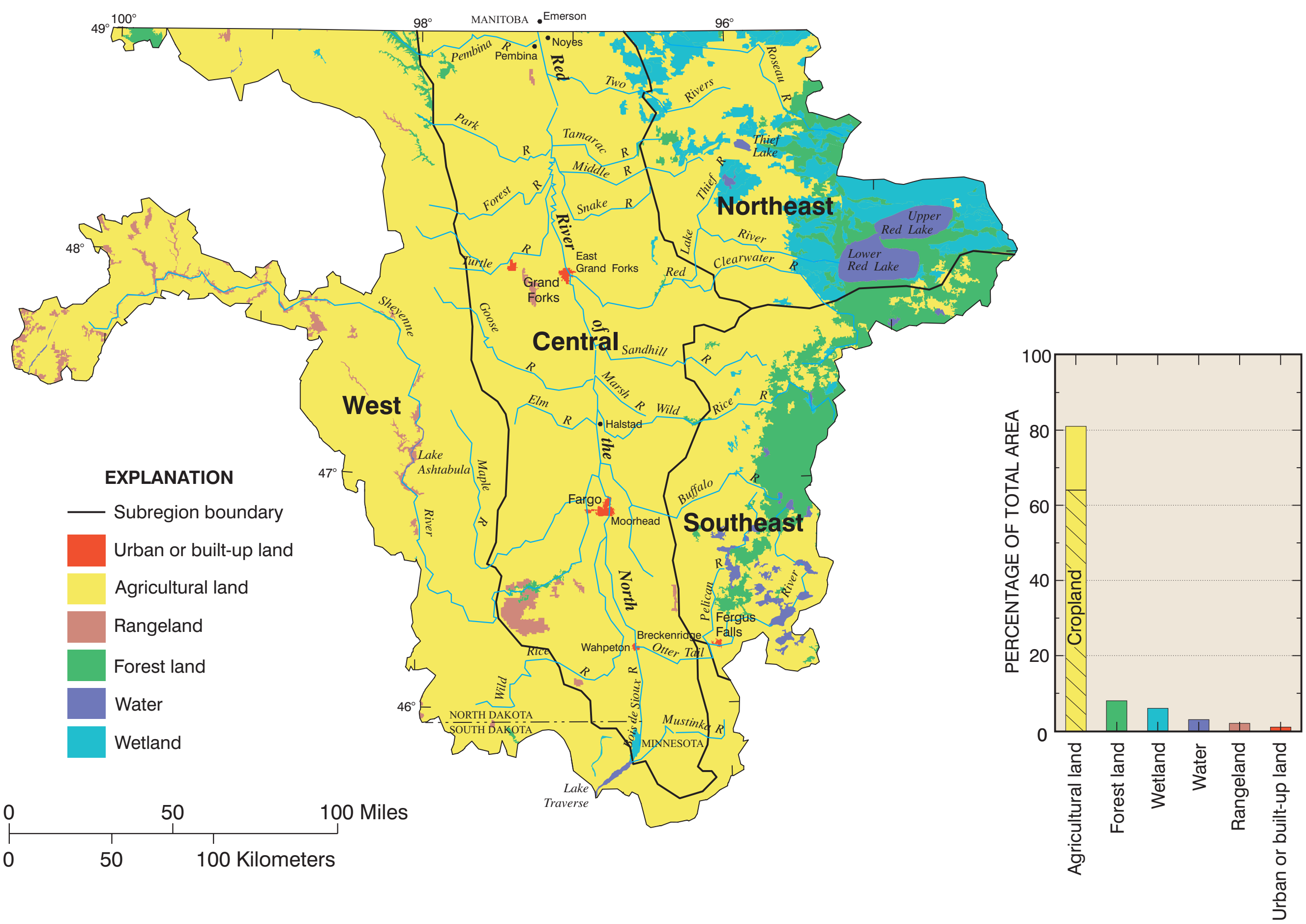


Figure 2. The major land use in the Red River of the North Basin Study Unit is agriculture.

The 1990 population in the largely rural Red River Basin Study Unit was about 511,000. Almost one-third of the population lives along the Red River in the cities of Fargo and Grand Forks, North Dakota, and Moorhead, Minnesota. Urban runoff, treated municipal waste, and treated industrial waste from these and other cities can contain turf-applied pesticides, organic compounds, and nutrients that are discharged into the river.

Knowledge of land-use type and location is important because pesticides and nutrients applied to the soil and crops can leach into ground water or enter streams through runoff. About 81 percent of the land area in the Study Unit is agricultural, and 64 percent of the total area is cropland (fig. 2). Principal crops are wheat, barley, corn, and soybeans. Secondary crops include oats, sugar beets, sunflowers, potatoes, and forage grasses. Most nonagricultural land is along the eastern edge of the Study Unit.

Good quality water is important for residents in the Study Unit. In 1990, about 36 percent of the withdrawals from surface water in the basin were used for public supply (Stoner and others, 1993). Most of these withdrawals were from the Red River by Fargo and Grand Forks, North Dakota, and Moorhead, Minnesota, the major urban areas in the basin. Public supplies also came from ground water. In rural areas, water for domestic use was obtained almost exclusively from glacial sand and gravel aquifers. All public drinking water should meet standards to protect the health of the population and preferably have no objectionable taste or odor. Water use also can affect water quality. For example, irrigation, accounting for 47 percent of all 1990 water withdrawals (fig. 3), can increase leaching of salts and agricultural chemicals into shallow ground water.

Streamflow generally was above average during the 1993–95 period of sampling. The spring peaks for 1993 and 1994 were generally within the 25th and 75th percentile of flow (fig. 4), and the peak for 1995 was above the 75th percentile of flow. Summer storms produced streamflows much larger than the 75th percentile in each of the sampling years, with the storms of 1993 resulting in very large flow. Large summer rainfalls can remove nutrients and pesticides applied after the spring snowmelt and result in larger than normal concentrations and loads of these constituents in streams. Spring peak flows can contain pesticides applied in the fall and nutrients leached from decaying matter and soils.

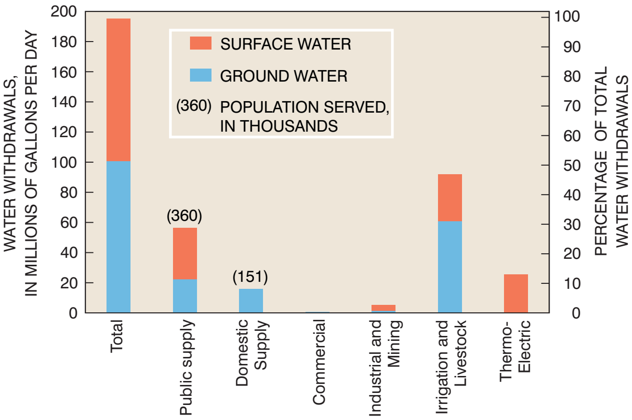


Figure 3. Overall water use in 1990 generally was balanced between surface and ground-water sources.

Ground-water levels generally were high during the 1993–95 period of sampling. Drought conditions that lasted from 1987 into 1991 preceded this sampling. Ground-water levels generally rose from the end of the drought to the time of sampling as a result of increased recharge. This rise can be seen in the hydrograph for a well located in the southeast subregion (fig. 5). Recharge can affect the quality of shallow ground water. The quality of shallow ground water is affected by land-use activities and relatively recent (0–10 years) recharge. However, the quality of deeper ground water, which typically is older than 20 years, is less affected by relatively recent land-use activities and recharge.

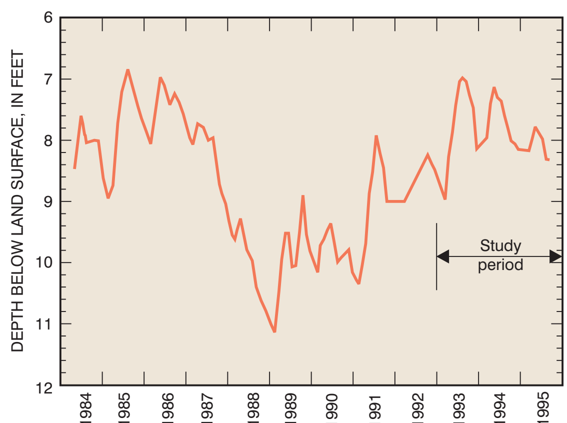


Figure 5. Ground-water levels generally were high during the study period.

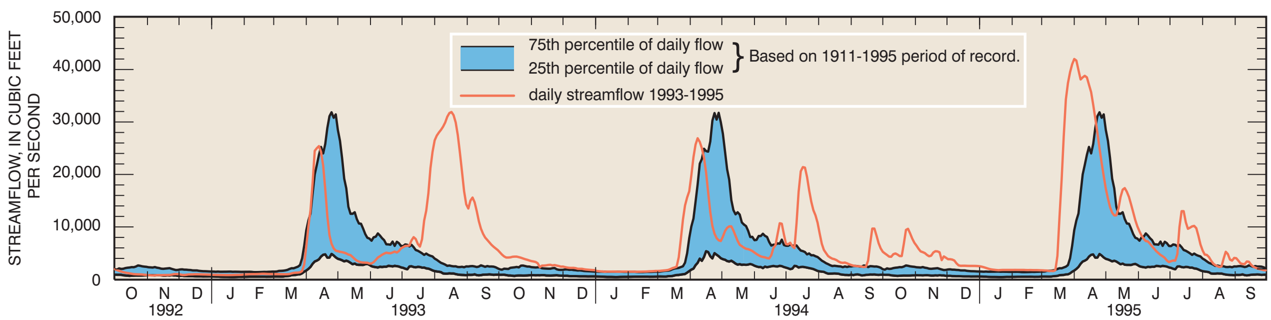


Figure 4. Daily streamflow in the Red River of the North at Emerson, Manitoba, shows above-normal flows during the study period.

Defining background conditions of water quality is important for water and land managers in assessing the effects of human activities, such as land use, on water resources. The background dissolved solids in rivers and ground water in the Red River Basin Study Unit include the major cations (calcium, magnesium, sodium, and potassium), the major anions (bicarbonate, chloride, and sulfate), trace elements (including iron and manganese), and radionuclides (uranium, radium, and radon). The most common ions in ground water from surficial and buried glacial aquifers are calcium, magnesium, and bicarbonate, all of which are at fairly low concentrations. Median dissolved solids are about 400 milligrams per liter (mg/L) for surficial glacial aquifers and 500 mg/L for buried glacial aquifers. Common ions in deeper bedrock aquifers are sodium and chloride (the components of table salt) and are at much higher concentrations (median dissolved-solids concentration about 1,900 mg/L).

Ground-water studies in the Study Unit demonstrated that water quality in surficial aquifers in the west and central subregions is significantly different than that in the southeast subregion (Cowdery, in press). These differences are in the concentrations of dissolved solids, sodium, sulfate, silica, potassium, uranium, and radium. The west and central subregions have higher concentrations of all of these ions except radium, which is higher in the east. Variations in water quality are related to natural differences in geology and hydrology. Saline sedimentary bedrock aquifers exist mostly in the western part of the Study Unit (fig. 6). Most of the eastern part is underlain by crystalline rocks that do not readily transmit water and were not considered for this study. The sedimentary bedrock aquifers slope gently upward to the east, in the direction of regional ground-water flow. Saline water from these aquifers is primarily discharged in the north-central part of the Study Unit. Saline ground water from deep aquifers seeping into some shallow buried and surficial aquifers in the west and central subregions can affect the quality and use of water in these aquifers. This saline ground water also can discharge into streams and degrade water quality in the northwestern part of the Study Unit. This effect can be greatest during periods of extremely low streamflow.

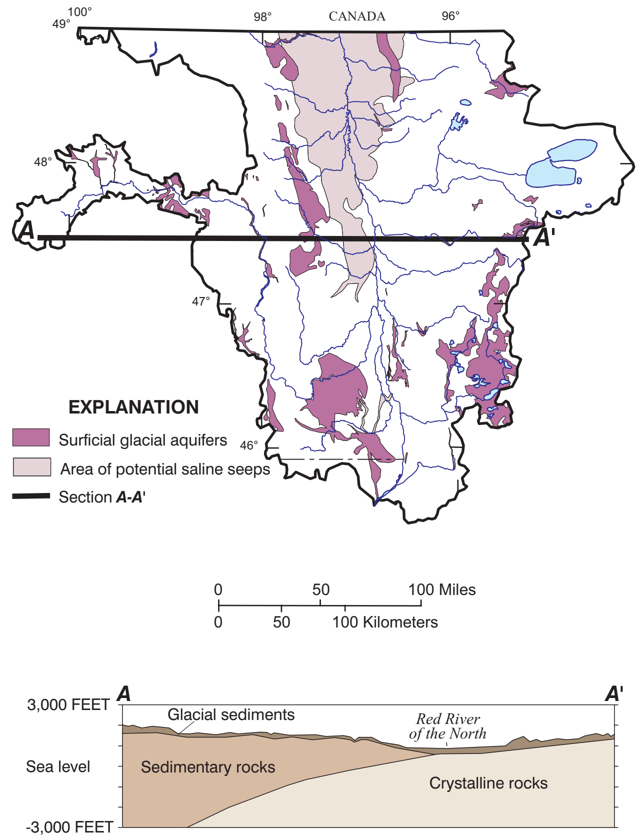


Figure 6. Surficial aquifers are in glacial sediments throughout the Study Unit. Saline ground water in sedimentary rocks can seep to the land surface.

The middle part of the Wild Rice River in Minnesota shows the relatively common undisturbed land in the southeastern subregion.

Most water in the Red River Basin Study Unit is safe to drink according to U.S. Environmental Protection Agency (USEPA) standards for natural constituents (dissolved solids, major ions, and radionuclides).

Some constituents of ground water in the Study Unit exceeded USEPA drinking-water standards (table1). These standards were exceeded in concentrations of primarily naturally occurring substances. Iron and manganese, which commonly occur in soluble minerals within glacial sediments, result in numerous exceedances of secondary maximum contaminant levels for these constituents in ground water. Radon concentrations were relatively consistent across the Study Unit. There is now no standard for radon in drinking water. USEPA withdrew the previous standard of 300 picocuris per liter (pCi/L) pending further review. More shallow ground water in the west and central subregions exceeds standards than does ground water in the southeast subregion (table 1). More water from buried sand and gravel aquifers exceeds standards than does water in surficial aquifers. In fact, more than 50 percent of the water in buried sand and gravel aquifers sampled exceeded the dissolved-solids standard and ranked among the highest nationally (p. 21). Although nitrate does occur naturally in ground water, background concentrations were not established in this study. Ground-water nitrate concentrations ranked among the lowest nationally (p. 20).

The distribution and concentration of major ions in streams appeared related to subregions in the Red River Basin Study Unit (Tornes and others, 1997). Historically, water in the Red River had mean dissolved-solids concentrations of 347 mg/L near the headwaters and 406 mg/L at the international boundary near Emerson, Manitoba (Stoner and others, 1993). The median dissolved-solids concentration at Emerson, Manitoba, was 419 mg/L during 1993–95 (Tornes and others, 1997), a period of relatively high streamflow conditions. With limited area of undisturbed land in the Red River Basin Study Unit, background conditions in stream-water quality were not definable.

Fish communities and stream habitat can be indicators of overall stream quality. For example, greater fish species diversity and abundance coincide with higher quality streams. Fish diversity and abundance in the streams of the Study Unit are influenced by human and natural factors (Goldstein and others, 1996b). Three factors explain about 60 percent of the variability in fish distribution: (1) the abundance and diversity of fish habitat within a stream, (2) the variability in the amount of water in the stream, and (3) the amount of relatively undisturbed land (forest or wetland) within about a mile of a stream. Habitat and stream variability are mostly natural factors, although both are influenced by human activities. Other factors considered in this study, such as number of dams, amount of drainage ditches, or width of riparian buffer zones, appear to have less effect on variability in fish distribution and abundance (Goldstein and others, 1996b).

Table 1. Some U.S. Environmental Protection Agency drinking-water standards and health advisories were exceeded frequently in ground water in the Red River Basin Study Unit

[Green area, maximum contaminant level; yellow area, secondary maximum contaminant level; mg/L, milligrams per liter; pCi/L, picocuries per liter]

Constituent	U.S. Environmental Protection Agency standards and health advisories	Percentage of ground-water samples exceeding standard or advisory				
		Glacial aquifer type		Subregion		
		Buried	Surficial	West	Central	Southeast
Dissolved solids, in mg/L	500	52	23	33	38	0
Sodium, in mg/L	[1]20	82	21	27	33	4
Chloride, in mg/L	250	9	0	0	0	0
Sulfate, in mg/L	500	6	3	7	4	0
Sulfate, in mg/L	250	12	5	7	7	0
Fluoride, in mg/L	[2]2	0	0	0	0	0
Iron, in mg/L	0.3	82	48	13	52	64
Manganese, in mg/L	0.05	82	79	80	85	72
Uranium, in mg/L	[3]0.02	0	5	7	8	0
Radium, in mg/L	[3]0.005	0	0	0	0	0
Radon, in pCi/L	[4]300	50	66	60	64	64

[1]Health advisory.
[2]Under review.
[3]Proposed.
[4]Historical, under review.

This study focused on the relation between land use and water quality. Agriculture, and particularly crop production, is the primary use of land in the Red River Basin Study Unit. Streams and surficial sand and gravel aquifers are vulnerable to the effects of agricultural activities. These resources are important for public and commercial uses.

Nutrients detected in streams and pesticides detected in streams and water in surficial aquifers did not exceed any existing drinking-water standards and, except for a single instance for triallate, were not toxic to aquatic life.

A single sample from the Snake River (fig. 2) contained a triallate concentration of 0.28 microgram per liter (µg/L), which exceeded the interim Canadian guidelines for the protection of freshwater aquatic life (Canadian Council of Ministers of the Environment, 1992). Twenty-seven percent of the ground water sampled in the west subregion and 8 percent of the ground water in the southeast subregion exceeded the 10-mg/L drinking-water standard for nitrate (Cowdery, in press). None of the ground water in the central subregion exceeded the drinking-water standard for nitrate. Currently (1998), USEPA drinking-water standards exist for 7 of the 44 pesticides detected in the basin. No ground water exceeded any of the existing standards. Pesticide and nutrient persistence and regional differences in soils, geology, and climate govern the distribution of these water-quality indicators in the Red River Basin Study Unit (Tornes and others, 1997; Cowdery, 1997; and Cowdery, in press). Data from this study and previous studies were not sufficient to determine changes in pesticide levels over time. Continued monitoring might help to satisfy concerns about pesticide trends in water.

Streams draining areas of extensive cropland (central and southern parts of the Study Unit) had the highest concentrations of nutrients (dissolved phosphorus, nitrate, and organic nitrogen) and the most detections of herbicides (Tornes and others, 1997). No stream water exceeded any of the existing drinking-water standards for pesticides or nutrients.

Table 2 shows that selected indicators of water quality varied across the four subregions, which generally relate to major categories of land use (fig. 2). The water-quality indicators used are commonly associated with agricultural land use but are also affected by environmental conditions, such as geology, soils, climate and hydrology.

Pesticide concentrations in water are not related only to amounts used in agriculture.

Despite having a drainage area composed of 64 percent cropland, the Red River delivered relatively low concentrations and loads of pesticides into Canada (table 3). Pesticide concentrations in water commonly were related to the drainage of water over and through agricultural soils, pesticide uptake by plants and microbes, and attachment to soil particles.

Table 2. Water quality varies by major subregions in the Red River Basin Study Unit

[SW, surface water; GW, ground water (surficial aquifers); --, not sampled; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than]

<table>
<tr><th rowspan="3" colspan="2">Water-quality indicator</th><th rowspan="3">Water resource</th><th colspan="4">Value</th><th rowspan="3">Remarks or specific findings</th></tr>
<tr><th colspan="4">Subregion</th></tr>
<tr><th>West</th><th>Central</th><th>Northeast</th><th>Southeast</th></tr>
<tr><td rowspan="2" colspan="2">Mean total pesticides, (mostly herbicides) (µg/L)</td><td>SW</td><td>0.36</td><td>0.17</td><td>--</td><td>0.23</td><td rowspan="2">Central does not include the Red River as an indicator of this subregion.
Southeast had highest percent detection rate, but values were all low.</td></tr>
<tr><td>GW</td><td>.01</td><td>.05</td><td>--</td><td>.03</td></tr>
<tr><td rowspan="4">Nutrients (mg/L)</td><td>Median total nitrogen</td><td>SW</td><td>.67</td><td>1.02</td><td>0.82</td><td>.59</td><td rowspan="4">The Red River is a major source of nutrients to Lake Winnipeg.
Nitrate concentrations in ground water exceeded the USEPA drinking-water standard in 27, 0, and 8 percent of samples in the west, central, and southeast subregions, respectively.
Minnesota Pollution Control Agency goal is 0.10 mg/L phosphorus in rivers.
Subregions with high nutrient levels do not necessarily have high pesticide levels.</td></tr>
<tr><td>Median nitrate nitrogen</td><td>GW</td><td>.39</td><td><.05</td><td>--</td><td><.05</td></tr>
<tr><td>Median total phosphorus</td><td>SW</td><td>.14</td><td>.14</td><td>.04</td><td>.03</td></tr>
<tr><td>Median orthophosphate (dissolved)</td><td>GW</td><td>.03</td><td>.01</td><td>--</td><td>.02</td></tr>
<tr><td colspan="2">Median Index of Biotic Integrity</td><td>SW</td><td>41</td><td>25</td><td>36</td><td>43</td><td>These scores were strongly related to stream habitat.</td></tr>
</table>

Table 3. The amount of pesticides in the Red River is a small percentage of the amount applied

[Units in pounds per year, except as indicated.]

Pesticide	Annual rate of application (1990)	Load at Emerson (1993–95)	Percent output
Atrazine	120,000	1,100	0.9
Triallate	450,000	270	.06
2,4-D	1,700,000	370	.02

The most heavily applied pesticides (2,4-D, MCPA, bromoxynil, and trifluralin) were not always the most frequently detected in streams and shallow aquifers (fig. 7 and tables 6 and 7, p. 24–26) (Tornes and others, 1997; Cowdery, in press). The infrequency of 2,4-D detection may be related to factors such as the following: (1) 2,4-D is applied as a post-emergent herbicide and mostly is taken up by plants where it is metabolized to other compounds, (2) soil microbes effectively degrade 2,4-D, or (3) soils retain 2,4-D instead of allowing it to run off or seep downward into ground water (Tornes and others, 1997). Triallate was detected in northern streams of the Study Unit, an area where it is most commonly applied to small grains. Triallate usually was applied during autumn and reached streams during spring snowmelt runoff.

Wheat harvest is a major agricultural activity in August (photograph courtesy of Don Brennemen, University of Minnesota Agricultural Extension Service).

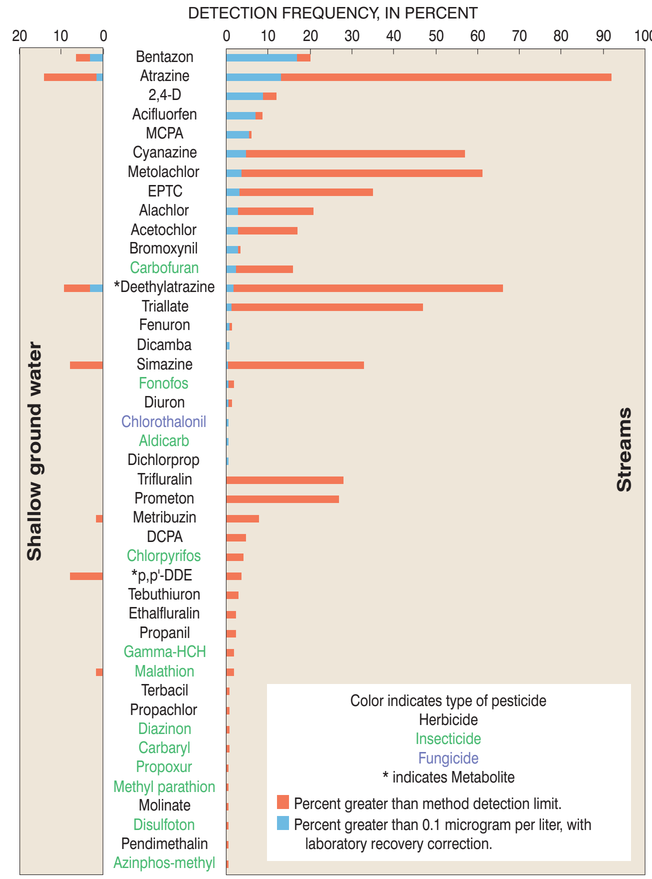


Figure 7. More pesticides were detected in streams than in shallow surficial ground water, and most were herbicides.

Some pesticides were ubiquitous.

Atrazine, applied on corn mostly in the southern part of the basin, and its metabolite, deethylatrazine, were the most frequently detected pesticides in streams throughout the basin and shallow ground water beneath cropland. Atrazine was detected in nearly every stream sample collected from the basin, even during winter. Simazine, commonly applied for weed control in rights-of-way in the Study Unit, also was detected frequently in streams and shallow ground water. Although DDT was banned for use in the United States more than 20 years ago, low concentrations of DDT and its metabolites were detected in stream sediments and fish tissues (Goldstein and others, 1996a; Brigham and others, 1996). The metabolite p,p'-DDE was detected in some ground water and streams. DDT and its metabolites are more prevalent in agricultural areas, indicating that residue from past DDT use is a more prevalent source than atmospheric transport from distant sources (outside of the Red River Basin Study Unit).

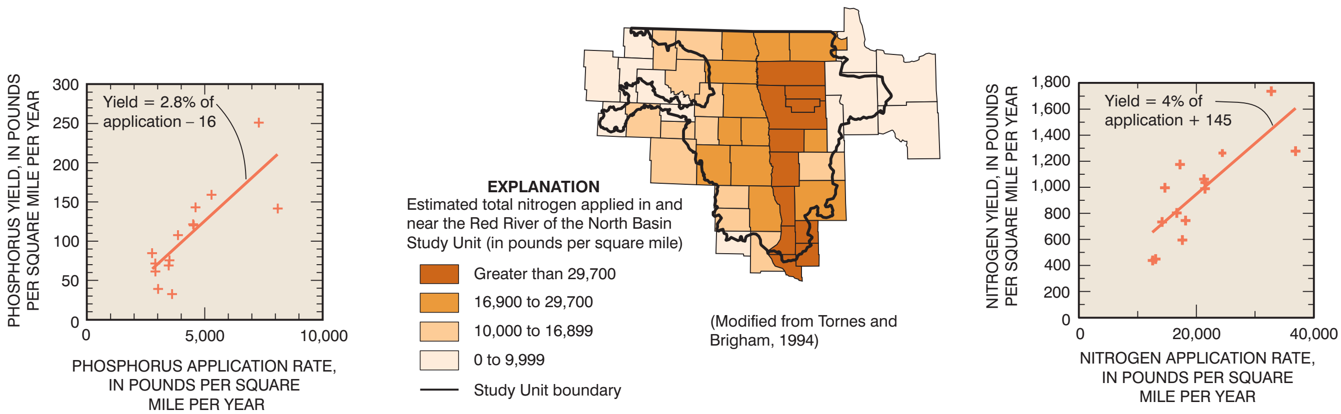


Figure 8. Cropland applications of nitrogen and phosphorus have contributed nutrients to streams (1993-95).

Cropland activity has contributed to nutrients found in streams and shallow ground water.

Nutrient concentrations were relatively low, but cropland activity has increased the amount of nutrients (particularly phosphorus) available to aquatic plants in streams (fig. 8). Phosphorus concentrations occasionally were high enough to produce eutrophic conditions in streams and receiving waters, such as lakes and wetlands. For example, streams draining the western and central parts of the basin (mostly cropland) had the highest concentrations of total phosphorus—0.12 to 0.32 mg/L. Streams draining the eastern part of the basin (where the percent cropland is smaller) had the lowest total phosphorus concentrations—0.08 mg/L or less. Concentrations of dissolved and suspended phosphorus increased substantially during runoff after snowmelt and rainfall. High phosphorus concentrations in the Pembina River probably resulted from agricultural applications and naturally occurring phosphorus in soils that is readily delivered to this river because of steep terrain in the watershed. From 1975 to 1988, 60 percent of the phosphorus load to Lake Winnipeg by the Red River came from the U.S. portion of the Red River Basin (Brigham and others, 1996).

The median concentration of nitrate was higher in the Red River than in the tributaries (fig. 9). These values indicate that activities in and near the Red River are contributing to the nitrate concentrations in the river. These activities could be both agricultural and nonagricultural.

Generally, water in aquifers sampled for the Red River Basin Study Unit is safe to drink relative to nutrients and herbicides (Cowdery, in press) (fig. 10). As related to agricultural pesticide application, volatile organic compounds (VOCs) were not detected in surficial aquifers (Cowdery, 1997; Cowdery, in press). Concentrations of pesticides and nutrients in water from the buried aquifers, naturally protected by overlying sediments, indicated no significant contamination from irrigation (Cowdery, in press).

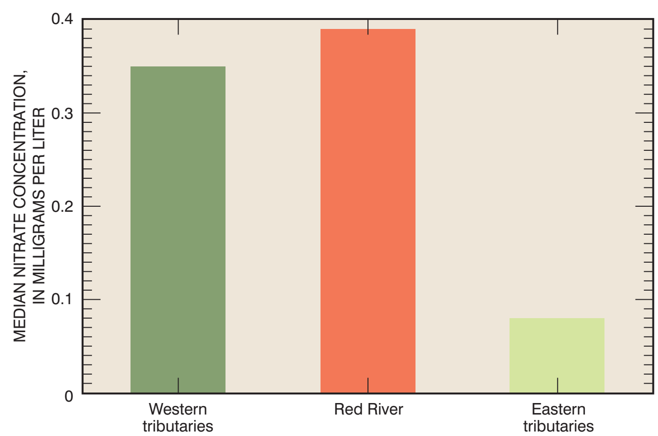


Figure 9. Nitrate concentration in streams differed by subregion in the Study Unit.

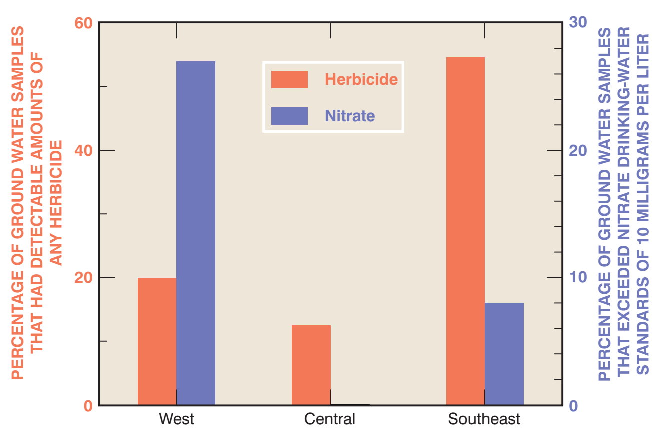


Figure 10. Agricultural chemical concentrations in ground water differed by subregion in the Study Unit.

Detections of pesticides and nitrate in shallow ground water were related to cropland in sandy soils over coarse-textured aquifers.

Nitrate concentrations near the water table exceeded the drinking-water standard (10 mg/L) in some areas but decreased significantly at greater depths in the surficial aquifers (Cowdery, 1997). Irrigation has enhanced crop production in some areas by allowing for increased yields and a greater variety of crops. Increased applications of fertilizer and pesticides are sometimes associated with irrigation. Irrigation has also been associated with pesticides and nutrients reaching parts of some surficial aquifers. The concentrations of pesticides in shallow ground water in the irrigated parts of the Otter Tail outwash aquifer (fig. 11) are higher than elsewhere in the Study Unit and indicate the potential for contamination in deeper ground water (Cowdery, 1997).

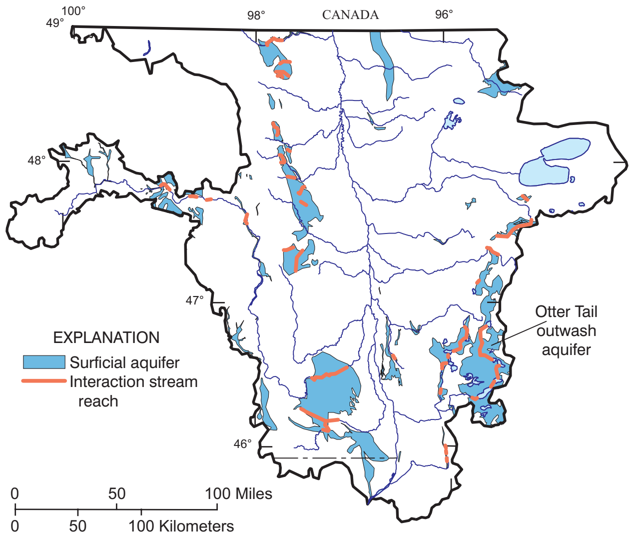


Figure 11. Several sites of possible stream-aquifer interaction occur in the Red River of the North Basin Study Unit.

A detailed study of the Otter Tail outwash aquifer (see page 22) that included analyses of ground-water age, water chemistry, and historical land use showed a trend of increased nitrate and nitrogen levels over the past 30 years (Stoner and others, 1997). The combination of irrigation, sandy soils, aquifer materials with low carbon content, and conditions not favorable for biological reduction of nitrate resulted in elevated nitrate in the shallow ground water.

The Otter Tail outwash aquifer, with high nitrate concentrations near the water table, discharged water with low nitrate concentrations to the Otter Tail River, according to one intensive case study (Puckett and others, 1995; Tornes and others, 1996; Stoner and others, 1997). Mixing with older, low-nitrate ground water and denitrification (whereby nitrate was transformed to nitrogen gas and removed from the water) as water flowed beneath riparian wetlands accounted for the low concentrations of nitrate discharging to the river. These conditions helped reduce the possibility of eutrophication in the river and downstream lakes and wetlands. Figure 11 shows other areas in the Study Unit where surficial aquifers potentially discharge water to streams.

A direct link between pesticides and nutrients in streams and fish communities was not established.

Fish were studied as part of the overall assessment of stream quality. Detailed analysis showed that both chemical and physical factors affect the composition of fish communities in the streams of the Study Unit. Specific cause-and-effect relations could not be established, however. Differences in fish communities could not be explained directly by differences in concentrations of nutrients and pesticides in streams in agricultural areas (Goldstein and others, 1996b). Only one pesticide (triallate) was detected in one stream sample that exceeded a level of concern for acute toxicity to aquatic organisms (Tornes and others, 1997). More work will be helpful to better assess the effects of nutrients on the aquatic food chain and the effects of pesticides on the reproductive abilities of fish (Goodbred and others, 1997).

Limitations of this assessment of agriculture and water quality should be recognized.

Some insecticides and most fungicides applied to specialty crops, such as potatoes and sugar beets, were not analyzed in this study; also, the results of this water-quality assessment likely were affected by the unusually wet summers that occurred during the period of intensive sampling (1993–95). Dilution or increased loads to streams or surficial aquifers were possible as a result of these wet conditions. Therefore, the relation established between agriculture and water quality during this study may not represent average conditions.

Fish distribution and abundance may not be a good indicator of nutrient effects on stream quality. Most of the nutrients enter the stream early in the spring when temperatures are low and most metabolic rates for aquatic plants and animals likewise are low. Therefore, the amount of nutrients applied in a watershed correlated poorly with fish distribution and abundance.

Currently (1998), drinking-water standards are set only for individual pesticides. However, pesticides commonly occur in mixtures of up to nine compounds in surface water that is a potential source of drinking water. Although most shallow ground water did not contain detectable concentrations of pesticides, more than one pesticide commonly was detected in water where there were detectable concentrations. The health effects of such combinations of pesticides in drinking water are not well understood. However, the effects of various pesticides on human health may differ when pesticides are present in combination, even at low concentrations, in drinking water. The USEPA (1994) is considering establishing drinking-water standards for combinations of triazine pesticides and their individual degradation products.

Although the major land use in the basin is agriculture, urban areas also can affect water quality. The primary sources of contamination from urban areas are stormwater runoff, municipal wastewater discharge, and industrial discharge. This study did not focus specifically on point discharges; but generally, water quality downstream from Fargo can be compared to the water quality upstream.

The concentrations of some indicators of nutrient contamination were slightly but measurably higher downstream from Fargo, North Dakota, and Moorhead, Minnesota, than upstream (Tornes and others, 1997).

The median concentrations of ammonia and total phosphorus were slightly higher in the Red River downstream from the Fargo-Moorhead area (fig. 12). This analysis was based on the discharge-weighted mean concentration of ammonia and total phosphorus upstream from the Fargo-Moorhead area and at Halstad (fig. 2).

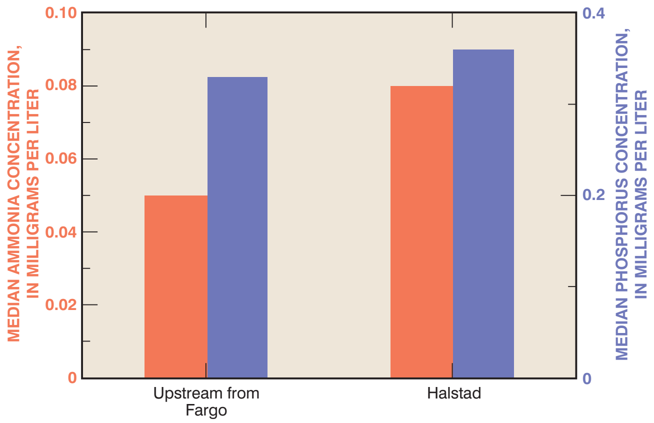


Figure 12. Ammonia and phosphorus concentrations in the Red River of the North increase in a downstream direction through the Fargo-Moorhead area.

The effect of municipal wastewater discharges on the total nitrogen concentration can be estimated through a mass balance model. In this model, the total nitrogen concentration is computed from the concentration in the average daily municipal wastewater-treatment outflow and the concentration in streamflow at the time of measurement. Adding the municipal wastewater outflow from Fargo and Moorhead increases the median total nitrogen concentration from 1.41 mg/L upstream from the Fargo-Moorhead area to 1.68 mg/L downstream (Tornes and others, 1997). The effect on the Red River is difficult to assess farther downstream because the streamflow nearly doubles between the Fargo-Moorhead area and Halstad, Minnesota. This analysis assumes a total nitrogen concentration of 11.2 mg/L for sewage effluent (national average, Larry Puckett, U.S. Geological Survey, written commun., 1993). This model may not be appropriate for conditions after September 1995 because a new sewage-treatment plant went into full service at that time.

Nitrite plus nitrate concentrations tended to be slightly higher than historical concentrations at sites along the Red River. Median ammonia concentrations for the Red River at Halstad, downstream from the Fargo-Moorhead urban area, were about 0.16 mg/L in historical samples, but were only 0.08 mg/L in samples collected for this study (Tornes and others, 1997). Increases in nitrate and decreases in ammonia have been identified in several streams nationwide, particularly downstream from urban areas; these trends likely reflect improved aeration of wastewater effluent, whereby ammonia is nitrified to nitrate. It also is possible that reduced loading of oxygen-demanding materials is allowing streams to remain aerated, decreasing the instream production of ammonia.

Although urban areas contribute only a portion of the phosphorus in the Red River (fig. 12), it is a major issue in Red River water quality. Eutrophication due to high concentrations of phosphorus is possible in streams and in Lake Winnipeg, into which the Red River flows (fig. 1). Noxious algal blooms have occurred frequently in Lake Winnipeg (Nielsen and others, 1996). From 1969 to 1974, the Red River contributed about 58 percent of the total phosphorus but only 9 percent of the total flow to Lake Winnipeg (Brunskill and others, 1980). More recently, from 1975 to 1988 the Red River contributed, on average, twice the phosphorus load but only one-fifth the flow of the Winnipeg River (the other major tributary to the southern part of Lake Winnipeg); furthermore, about 60 percent of the phosphorus load at the outflow of the Red River comes from the U.S. portion of the Red River Basin (Brigham and others, 1996).

The Fargo municipal outflow pipe discharged into the Red River of the North until September 1995 when a tertiary treatment system was completed (photograph by Edwin Wesolowski, USGS).

Fish tissues, streambed sediments, and water in shallow aquifers were examined for potentially toxic chemicals. Many of the chemicals are associated with modern industrial sources, which are relatively sparse in the largely rural Red River Basin Study Unit.

PCBs are a class of industrial compounds that have been banned in the United States because of their toxicity and persistence in the environment. PCBs are synthetic so there are no natural or background levels of these compounds. Atmospheric transport of mercury, PCBs, and PAHs may carry these contaminants far from their sources (reviewed by Brigham and others, 1998). VOCs include both synthetic chlorinated compounds and compounds of natural origin, such as components of petroleum. These compounds have been widely dispersed in the environment by human activity.

Many of the contaminants detected in the Study Unit are present in aquatic ecosystems worldwide. Mercury and PAHs occur naturally but also are released to the environment from industrial activities such as fossil-fuel combustion and garbage incineration (table 4).

Table 4. Mercury and PCB levels were analyzed in fish tissue; several water-quality indicators were used to assess nonpoint-source toxic compounds

Chemicals examined	Sources
Mercury	coal burning, waste incineration
Polychlorinated biphenyls (PCBs)	electrical transformers, other
Polycyclic aromatic hydrocarbons (PAHs)	fossil fuels, combustion by-products
Volatile organic compounds (VOCs)	industrial solvents, petroleum

Medium-sized carp (about 2–4 pounds) in the Red River had an average mercury concentration of 0.31 part per million (ppm) in the muscle (fillet) tissue. Smaller channel catfish (about 0.5–1 pound) had lower mercury levels, averaging 0.18 ppm (Goldstein and others, 1996a). These concentrations are in the moderate range of Minnesota's fish-consumption guidelines. Although fish from this study had mercury concentrations lower than the U.S. Food and Drug Administration's 1-ppm standard, larger catfish and other game fish from the Study Unit analyzed by the Minnesota Department of Natural Resources (1994) exceeded this standard.

Polychlorinated biphenyls were commonly detected in low concentrations in fish samples.

Few fish samples had PCB levels in the moderate range of fish-consumption guidelines (Brigham and others, 1998).

Northern pike are common game fish in lakes and rivers in the Red River Basin (photograph courtesy of Dennis Conroy).

Polycyclic aromatic hydrocarbons were widely detected in bed sediments.

Bed sediment samples at few sites had PAH levels that were potentially high enough to adversely affect aquatic organisms, based on published toxicity studies (reviewed in Brigham and others, 1998). See tables 8 and 9, p. 27–29, for specific PAH and other semivolatile organic compounds detected and their range of concentration.

Volatile organic compounds were rarely detected in shallow ground water and when detected were at concentrations well below USEPA drinking-water standards.

VOCs were sampled in shallow ground water mostly beneath agricultural areas and under ice conditions in the Red River. Most VOC concentrations were below detection limits. Compounds that are in gasoline were detected in one well. It is possible that the well was contaminated during construction, and that sample might not be representative of the ground water in the aquifer (Cowdery, 1997).

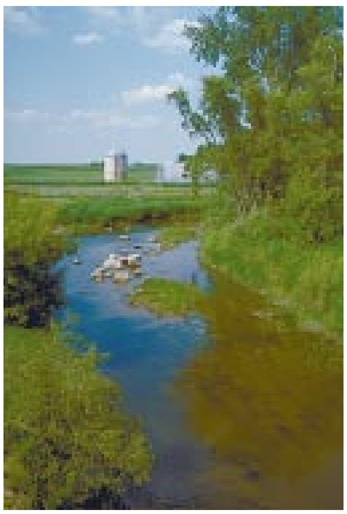
Fossil-fuel combustion is a major source of polycyclic aromatic hydrocarbons.

"The presence of sediment is one of the most obvious characteristics of small streams. Sediment has several forms and sources, but of greatest concern in stream and river sediment problems are the fine inorganic particles that either flow with the current (causing turbidity) or that are deposited on the streambed (causing loss of benthic productivity and fish habitat). Such sediment is widespread and pervasive, occurring to some extent in all streams."—Thomas F. Waters (1995)

"Obvious effects of ... anthropogenic erosion and sediment deposition include loss of agricultural soils, decreased water-retention capacity of forest lands, increased flood frequency, and rapid filling of reservoirs. Less obvious, however (and until recently largely ignored), is sedimentation in small streams that affects biotic communities, reduces diversity of fish and other animal communities, and lowers the productivity of aquatic populations." —Thomas F. Waters (1995)

Reprinted from "Sediment in streams—Sources, biological effects, and control" and published with permission.

Water with about 10 milligrams per liter suspended sediment (left) is much clearer than water with about 500 milligrams per liter (right) (photograph by Lan Tornes, USGS).



The upper reaches of the Wild Rice River is typical of many streams in the eastern part of the Red River Basin.

As the Wild Rice River flows downstream (shown near the confluence with the Red River), it becomes visually more turbid. Both photographs were taken in June 1992.

Water in the Red River is turbid, resulting from the fine suspended sediments (clay and silt). Suspended-sediment concentrations vary greatly in streams in the Study Unit due to factors such as landscape characteristics, streamflow, season, and land use. High suspended-sediment concentrations characterize streams that flow through heavily cropped, erodible lands (especially in the central part of the Study Unit) and erodible stream channels (especially the Pembina River). In contrast, low sediment concentrations characterize most streams that drain upland areas of the Study Unit. Most of these streams flow through reservoirs, lakes, and wetlands. Suspended sediments settle in these quiescent waters.

Suspended sediment in streams affects the chemical water quality. At high sediment concentrations, a significant portion of phosphorus and nitrogen in streams is attached to sediment. Organochlorines such as DDT and PCBs, and trace elements such as mercury and lead, adhere tightly to sediments, which can settle to the bottom of streams, lakes, and reservoirs. Organochlorines and trace elements were found in bed sediments during this study (Brigham and others, 1998) (see also tables 8 and 9, p. 27–29).

High sediment concentrations also diminish the esthetic water quality. The enjoyment of recreational activities such as fishing, swimming, and boating can be affected by sediment in the stream.

The highest sediment concentrations in each stream typically accompanied high flows (fig. 13). Therefore, sediment concentrations in streams are highest in the spring or after heavy summer rains.

The Otter Tail River flows through numerous lakes and reservoirs. Partly as a result of sedimentation in these quiescent water bodies, the river has low suspended-sediment concentrations.

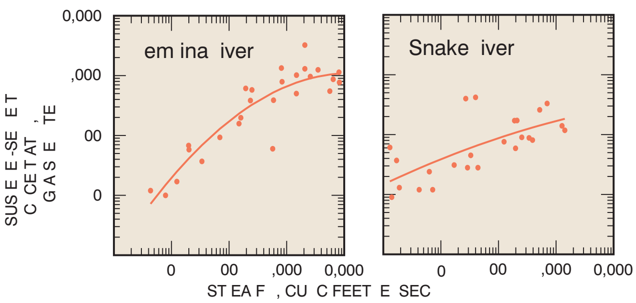


Figure 3. The em ina iver at alhalla, orth akota, had the highest suspended-sediment concentrations in all of the sampled streams. At the highest concentration, the river was carrying a out 30,000 tons of sediment per day. The Snake iver near Alvarado, innesota, is typical of central su region streams.

Land-use practices that do not abate rapid runoff of water can impair water quality by increasing suspended sediment in streams in two ways.

First, runoff erodes bare soils, which contributes sediment to streams. Second, higher streamflows associated with runoff events will more readily erode sediments from the channel and streambanks. The relative importance of these two sources of sediment is unknown for streams in the Red River Basin Study Unit.

Snowmelt runoff carries eroded sediment from a cultivated field to a drainage ditch (foreground). Sand, which is relatively coarse and heavy, settles at low flow velocities; finer silt and clay particles remain suspended at fairly low velocities. The stubble in this field probably helped lessen sediment erosion.

A high-flow event has deposited sediment on the flood plain (foreground) and on the lower part of the concrete structure separating these two culverts on Two Rivers near Northcote, Minnesota.

High flows erode the steep banks of the Pembina River, in northeastern North Dakota, contributing to the high sediment load.

Water-quality criteria and indicators used for monitoring and overall management of contamination sources for water resources in this basin could be enhanced by considering the water-quality effects of variation by subregion, hydrologic conditions, and season.

Nitrate concentrations in streams tended to be highest in the central subregion of the Study Unit (Tornes and others, 1997) where fertilizer application was the greatest (Tornes and Brigham, 1994). Total phosphorus also was higher in the central subregion than in the other subregions (Tornes and others, 1997). Atrazine and associated herbicides were detected mostly in the southern part of the basin where corn is a major crop. Streams in the western subregion had the highest concentrations of sulfate and usually the highest concentrations of dissolved solids. Dissolved-solids concentrations ranged from 300 mg/L in the upper Otter Tail River to about 800 mg/L in the Bois de Sioux River (Tornes and others, 1997).

This study was conducted during a period of relatively wet hydrologic conditions. These wet conditions enabled some definition of water quality during high streamflows and ground-water recharge. However, without comparable historical data, the specific effects of these wet conditions cannot be quantified.

Much of the temporal variation in water quality is seasonal. Seasonally, winter brings cold temperatures, snow, and ice. Surface waters tend to have less dissolved oxygen, lower concentrations of suspended sediment, and higher concentrations of nutrients than during other seasons. Ammonia and dissolved phosphorus concentrations can be high under ice conditions. Typical concentration of dissolved oxygen under ice was 0.1 mg/L in the Red River (Tornes and others, 1997).

Spring brings cool temperatures, melting snow and ice, flooded fields, and high flows in rivers with corresponding increases in dissolved-oxygen, suspended-sediment, and nutrient concentrations. Snowmelt and precipitation runoff delivers nutrients, pesticides, and sediment to streams. Soil preparation and the application of chemicals relative to the occurrence of precipitation accounts for some of the variability in the amount of contaminants that reached Study Unit streams. Agricultural chemicals such as triallate, a herbicide applied in the fall, may reach their highest concentrations during spring (Tornes and Brigham, 1995) (fig. 14).

Summer brings warm temperatures, thunderstorms, and generally declining water levels in rivers. The periodic rainstorms increase suspended sediment and transport pesticides applied in spring and summer to surface waters.

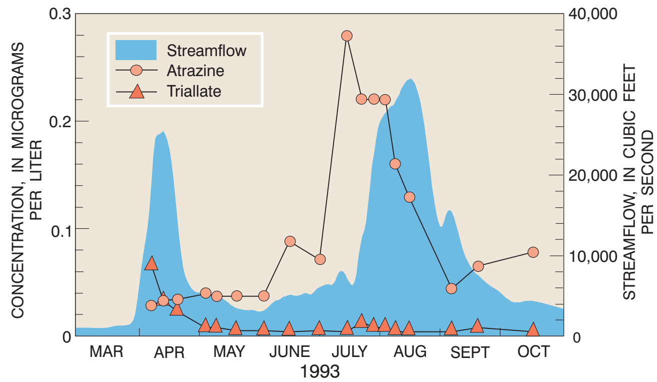


Figure 14. The concentration of pesticides in the Red River depends on the timing of their application and runoff from rainstorms or snowmelt.

Fall brings cool temperatures, falling leaves, and low streamwater levels. Streamflows approach the annual minimum during fall (Stoner and others, 1993). Reduced flows generally correspond to reduced suspended-sediment, nutrient, and pesticide concentrations.

Detailed studies of cropland effects on the quality of water in shallow surficial aquifers (Otter Tail and Sheyenne Delta study areas, p. 22) showed significant differences in pesticide presence and nitrate concentrations with location, season, and depth (Cowdery, 1997).

The median nitrate concentrations in ground water from the Otter Tail study were higher than from the Sheyenne Delta study: 6.1 mg/L compared to 0.03 mg/L, respectively. More pesticides were detected for the Otter Tail study and at higher concentrations than for the Sheyenne Delta study. The water-quality difference was related to differences in total nitrogen application to cropland (estimated at 52 and 23 pounds per acre per year, respectively) and slight differences in hydrologic and soil conditions among the aquifer settings. Although land use in both areas was similar, the Otter Tail aquifer received more recharge because of coarser textured soils and generally more irrigation.

Seasonal differences in nitrate concentrations in the upper 5 to 10 feet of these surficial aquifers were related in part to the timing of significant recharge periods that generally coincided with spring snowmelt and major summer rainstorms. This variable recharge, in conjunction with variations in the timing and application of fertilizer applied to each crop, results in complex changes in nitrate concentrations over time in shallow depths in these aquifers (fig. 15). Similar temporal variability in pesticide presence also might be expected. This information could be used in the design of ground-water monitoring of surficial aquifers for the purpose of checking the progress of land-management practices.

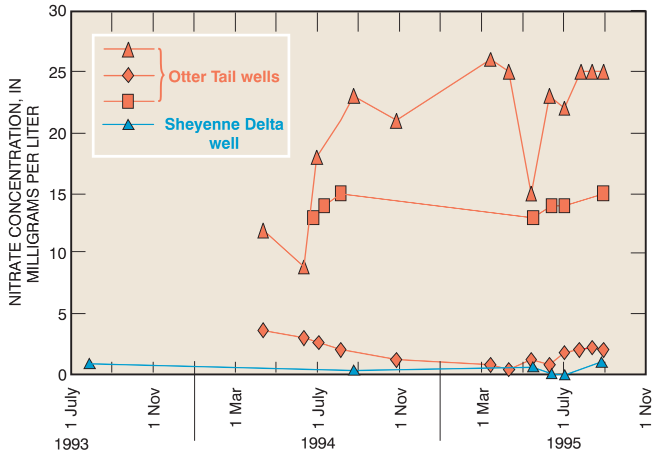


Figure 15. At shallow depth in surficial aquifers, nitrate concentrations sometimes varied with season.

Many privately owned drinking-water wells used in the Otter Tail and Sheyenne Delta aquifers are deeper than the monitoring wells from this study and produced water that was safe to drink. Water quality near the water table was affected by the land-use activities because of relatively recent recharge (1 to 10 years). The quality of the deeper ground water was older (greater than 20 years) and was therefore less affected by the relatively recent land-use practices and recharge (Stoner and others, 1997, and fig. 16).

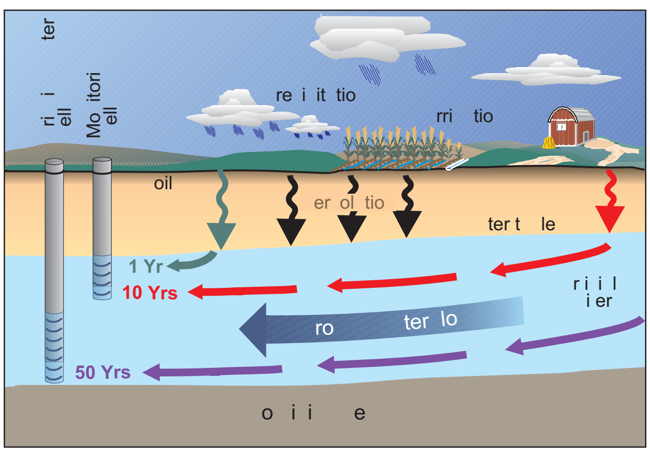


Figure 16. Ground-water monitoring that considers the use of wells completed near the water table could provide resource managers better opportunities to effect change in land-use practices before contamination spreads wider and deeper into an aquifer.

Fish community composition correlated well with stream size, habitat availability, and hydrologic variability, but not with geographic provinces and ecoregions (Goldstein and others, 1996b). Species in small streams, medium streams, and large rivers tend to differ (fig. 17). The source of species for tributary streams was the Red River, so any given species has potential access to most tributaries. The number of fish species (one measure of community health) increased with the size of streams and the number of ecoregions through which a stream flowed (Goldstein, 1995). Approximately 60 percent of the variability in fish community composition can be attributed to factors such as habitat, streamflow, water temperature, minimum dissolved-oxygen concentration, nutrients, and suspended sediment (Goldstein and others, 1996b). Additional variation was due to both human influence from land-use practices and biological interactions (competition, predation, disease, and parasitism) (Goldstein and others, 1996b). No patterns could be found to interpret cause-and-effect relations. Biological communities have adapted to take advantage of the environmental conditions that occur during each season: increased habitat volume and dissolved-oxygen concentrations during the spring for reproduction; increased water temperatures and productivity during summer for growth; lower water levels during fall for concentration of prey; and reduced activity and return to deep-water refuges during low water and dissolved-oxygen concentrations in winter (Goldstein and others, 1996b). A biological monitoring program (Niemela and others, in press) that relies on periodically sampling communities under the same seasonal environmental conditions has been developed for the Red River Basin Study Unit.

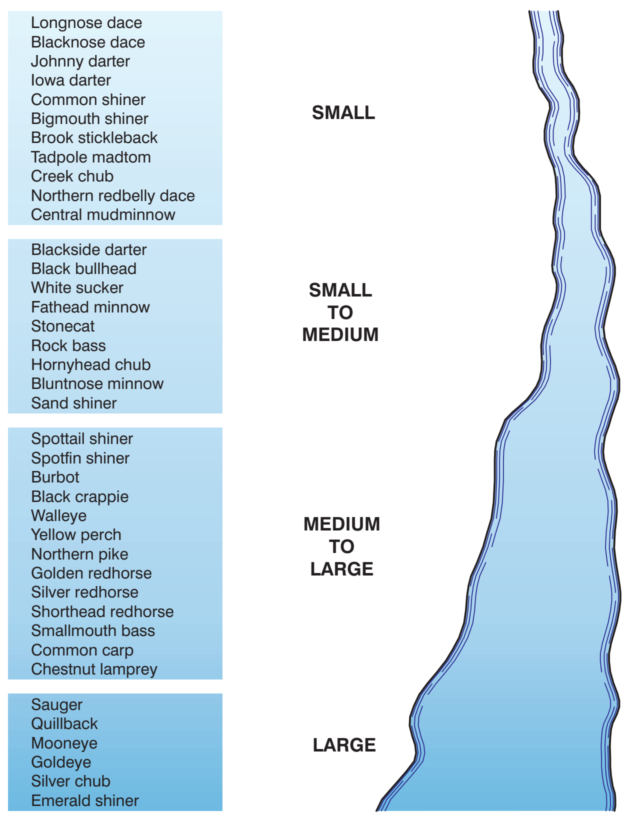
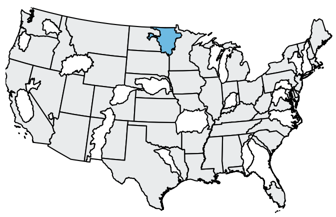
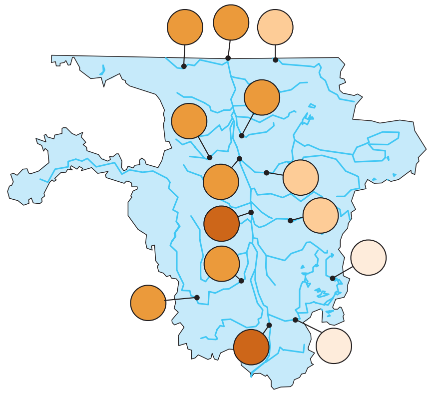


Figure 17. Fish species composition changes with stream size.



Seven major water-quality characteristics were evaluated for stream sites in each NAWQA Study Unit. Summary scores for each characteristic were computed for all sites that had adequate data. Scores for each site in the Red River of the North Basin were compared with scores for all sites sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA sites. Water-quality conditions at each site also are compared to established criteria for protection of aquatic life. Applicable criteria are limited to nutrients and pesticides in water, and semivolatile organic compounds, organochlorine pesticides, and PCBs in sediments. (Methods used to compute rankings and evaluate aquatic-life criteria are described by Gilliom and others, in press.)

NUTRIENTS in water



Nearly all streams that drain the eastern parts of the Study Unit contained nutrient concentrations that were lower than the national median for the other Study Units. Streams that drain the western and central areas were higher than the national median. The distribution of cropland and soils helps explain this nutrient pattern.

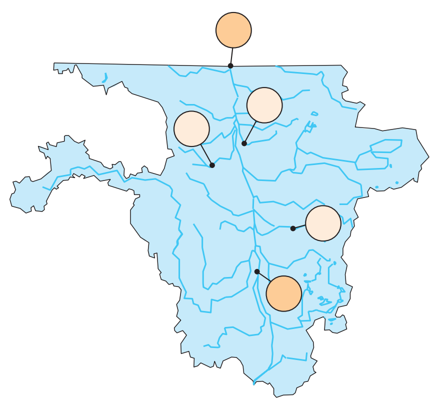
EXPLANATION

Ranking of stream quality relative to all NAWQA stream sites— Darker colored circles generally indicate poorer quality.

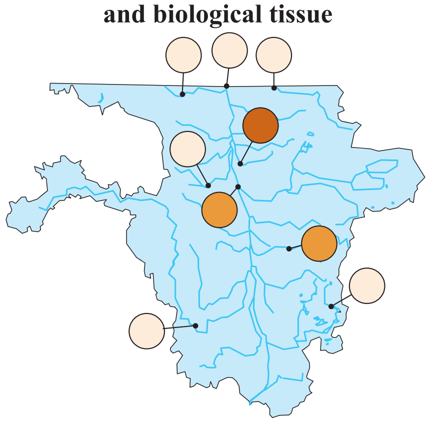
- **Greater than the 75th percentile** (among the highest 25 percent of NAWQA stream sites)
- **Between the median and the 75th percentile**
- **Between the 25th percentile and the median**
- **Less than the 25th percentile** (Among the lowest 25 percent of NAWQA stream sites)

PESTICIDES in water

Pesticide concentrations in the Red River and its tributaries are lower than most concentrations in streams from other NAWQA Study Units. The Study Unit had the highest percentage of agricultural cropland among other Study Units and is in the lowest quartile in terms of pesticide concentrations.

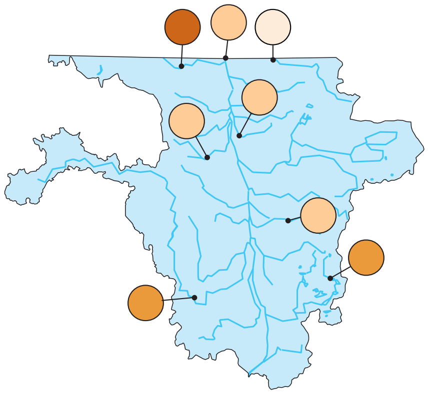


ORGANOCHLORINE PESTICIDES and PCBs in stream bed sediment and biological tissue



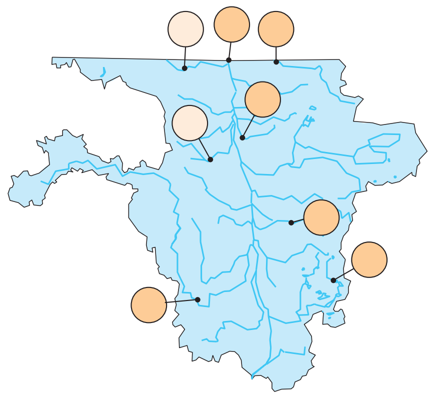
Where detected, DDT concentrations were typical of other minimally contaminated areas in the other NAWQA Study Units. Organochlorine concentrations in fish usually were low in the Study Unit and were low on a national basis. However, PCB concentrations in some fish from this area prompt State fish-consumption advisories. PCBs and many organochlorine compounds were banned in the 1970’s.

TRACE ELEMENTS in bed sediment



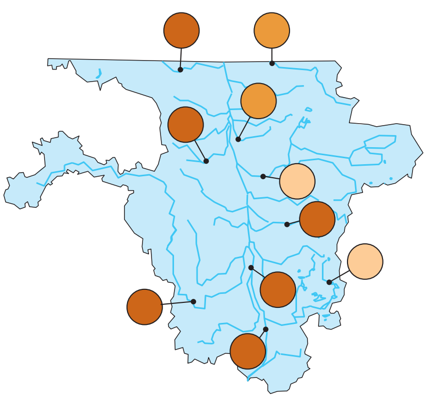
Trace elements in sediments were usually typical of other NAWQA Study Units and reflect natural concentrations. The site with the highest concentrations likely reflects higher natural concentrations of trace elements associated with shale outcroppings in that area.

SEMIVOLATILE ORGANIC COMPOUNDS in bed sediment



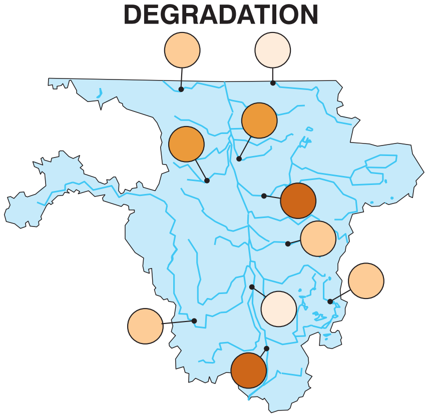
This broad group of chemicals includes PAHs (polycyclic aromatic hydrocarbons, which are both components of fossil fuels and by-products of combustion), phenols (industrial solvents), and phthalates (often used as plasticizers or solvents). concentrations of these compounds were below the median of other NAWQA Study Units.

STREAM HABITAT DEGRADATION



Stream habitat in the basin was generally poor compared to the other NAWQA Study Units. Almost all streams in the basin have been modified through dams, ditching, or channelization and erosion due to unstable banks. Agricultural practices that leave riverine wetlands and intact riparian zones with naturally dense vegetation seem to provide a degree of instream habitat protection and enhance fish communities.

FISH COMMUNITIES DEGRADATION



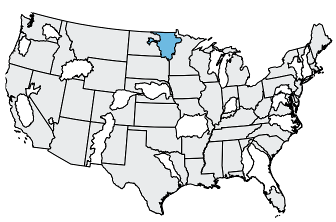
Compared to other NAQWA Study Units, fish species composition varied from poor to good, depending on area within the basin. Tributary streams outside of the central subregion tended to have better composition of species. Tributary streams in the central subregion and the Red River were dominated by introduced carp but still contained numerous species. It is difficult to distinguish the relative importance of natural compared to land-use factors due to the interactions where land use affects habitat and water quality.

CONCLUSIONS

The significant amount of cropland in the Red River Basin Study Unit has resulted in elevated concentrations of nutrients and low concentrations of pesticides in many streams. However, comparison to the NAWQA sites nationwide shows that nutrient concentrations were not exceptionally high and pesticide detections were relatively low.

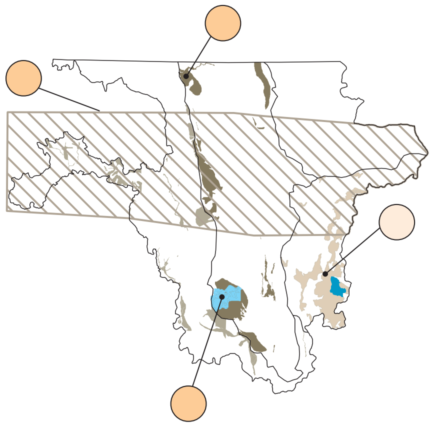
The presence of other toxic compounds in bed sediments or fish tissue were typical of other areas nationally. Aquatic-life criteria were not exceeded.

The distribution of trace elements is mostly affected by geology. Fish communities and habitat are relatively poor and are related both to natural conditions and land-use practices.



Five major water-quality characteristics were evaluated for ground-water studies in each NAWQA Study Unit. Ground-water resources were divided into two categories: (1) drinking-water aquifers, and (2) shallow ground water underlying agricultural or urban areas. Summary scores were computed for each characteristic for all aquifers and shallow ground-water areas that had adequate data. Scores for each aquifer and shallow ground-water area in the Red River of the North Basin were compared with scores for all aquifers and shallow ground-water areas sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA ground-water studies. Water-quality conditions for each drinking-water aquifer also are compared to established drinking-water standards and criteria for protection of human health. (Methods used to compute rankings and evaluate standards and criteria are described by Gilliom and others, in press.)

RADON



All radon concentrations ranked in the lower 50 percent of the samples collected from other NAWQA Study Units. Currently (1998), there are no Federal drinking-water standards for radon. The historical standard was exceeded in two-thirds and one-half of the samples collected from the surficial and buried aquifers, respectively.

EXPLANATION

Drinking-water aquifers

Surficial aquifers (Northeastern subregion was not studied)

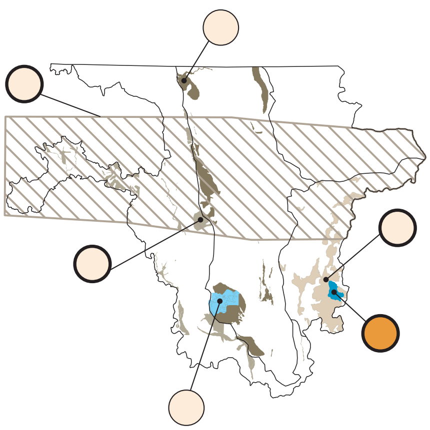
- **West**
- **Central**
- **Southeast**

Buried glacial aquifer sampled area

Shallow ground-water study areas

- **Sheyenne Delta**
- **Otter Tail outwash**

NITRATE

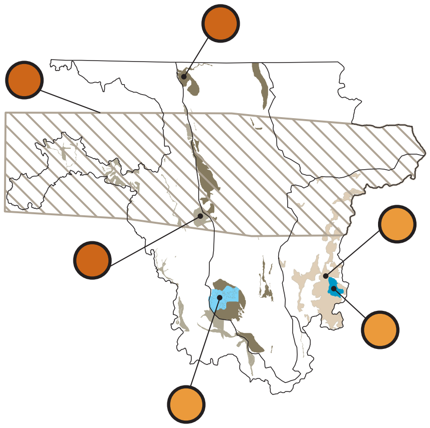


Although nitrate concentrations generally were low in comparison to other Study Units, the variability of nitrate concentrations was high. This explains why 27, 8, and 6 percent of the samples from the western and southeastern surficial aquifers and the buried aquifers, respectively, exceeded the USEPA drinking-water standard, whereas a much larger percentage of samples from these aquifers had concentrations close to or below detection limits. Nitrate concentrations in shallow ground water of the Otter Tail Outwash agricultural area ranked in the upper 50 percent among other Study Units.

Ranking of ground-water quality relative to all NAWQA ground-water studies— Darker colored circles generally indicate poorer quality. Bold outline indicates one or more drinking-water standards or criteria were exceeded

- **Greater than the 75th percentile** (Among the highest 25 percent of NAWQA ground-water studies)
- **Between the median and the 75th percentile**
- **Between the 25th percentile and the median**
- **Less than the 25th percentile** (Among the lowest 25 percent of NAWQA ground-water studies)

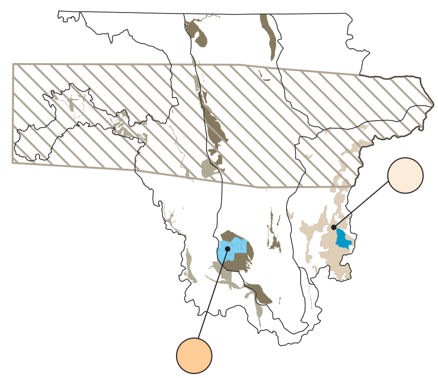
DISSOLVED SOLIDS



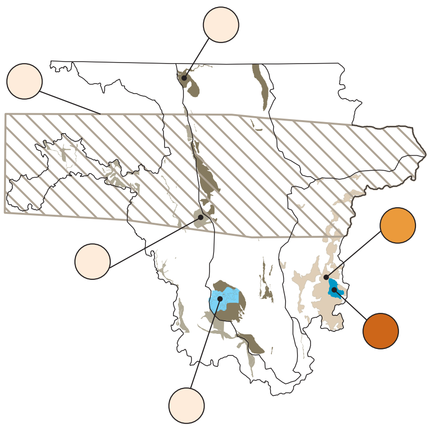
Dissolved-solids concentrations ranked in the upper 50 percent of the samples collected from other NAWQA Study Units. These concentrations were highest in the surficial aquifers located in the western and central subregions and in the buried aquifers sampled. These dissolved-solids concentrations, which largely reflect the effect of geology and semiarid climate, exceeded the drinking-water standard in more than one-third of the ground water sampled basin wide and from 14 to 17 percent of the shallow ground water sampled in the two agricultural areas studied.

VOLATILE ORGANIC COMPOUNDS (VOCs)

Of the two areas studied, VOCs were detected in only one well (Sheyenne Delta agricultural area), placing the Study Unit among the lowest compared to other NAWQA Study Units for VOC detections.



PESTICIDES



The number and concentrations of pesticides (mostly atrazine and related herbicides and bentazon) were relatively low with the exception of shallow ground water in the Otter Tail outwash area. Although no drinking-water standard was exceeded in the Otter Tail study, pesticide detections ranked among the highest in detections compared to other NAWQA Study Units (highest quartile).

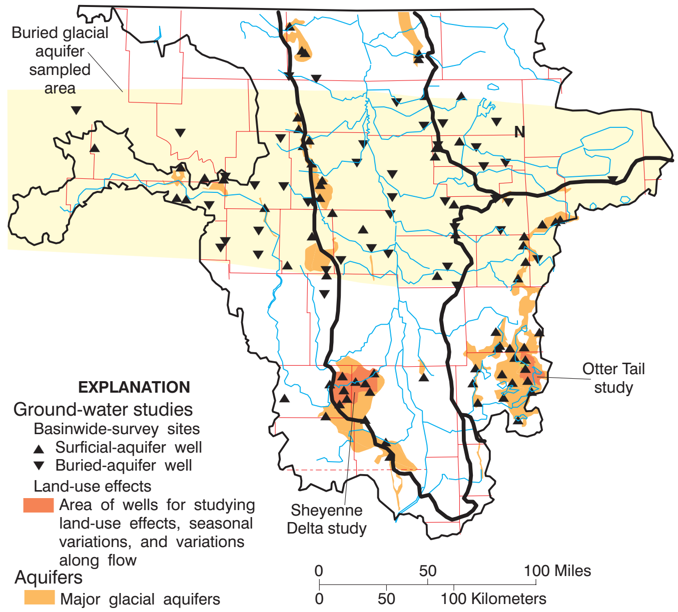
CONCLUSIONS

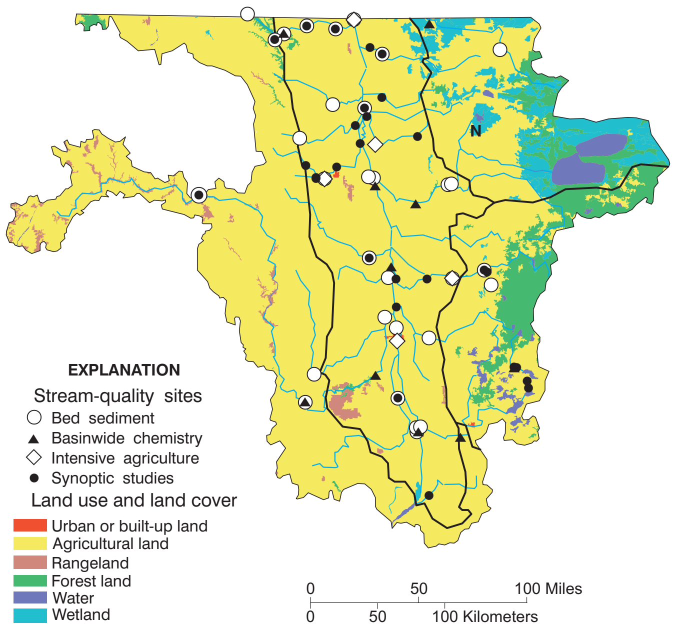
Given the large area of agricultural cropland in the Red River Basin Study Unit, pesticide detections and nitrate concentrations in ground water were relatively low compared to the other NAWQA Study Units.

For the Otter Tail outwash area, where sandy soils over relatively permeable surficial aquifers have been irrigated to enhance crop production, shallow ground water has been contaminated with pesticides and nitrate. These results show the importance of considering the geology along with agricultural and water-management practices in protecting ground-water quality.

The geology and semiarid climate of the western part of the basin result in dissolved-solids concentrations that are among the highest in the NAWQA Study Units. However, these concentrations are not a serious health risk for drinking water. They can result in esthetic nuisances, such as scale buildup, staining, and unpleasant taste.

The ground-water studies assessed the overall water quality of surficial aquifers and buried glacial aquifers (table 5). Land-use effects on ground-water quality were also described in two study areas. A special study addressed land-use effects on the Otter Tail outwash aquifer along ground-water flow from areas of recharge beneath the land use to an area of discharge to a stream.





The stream-water-quality sampling design (table 5) was established to assess the effects of agricultural land use on water quality and account for differences in the four subregions. A special study addressed the capacity of suspended sediment for transporting nutrients in streams.

Aquatic biology sites were selected to describe the variation among the USEPA ecological regions (Omernik, 1987) in the Study Unit (table 5). Samples were also taken to determine the presence of contaminants in fish tissue.

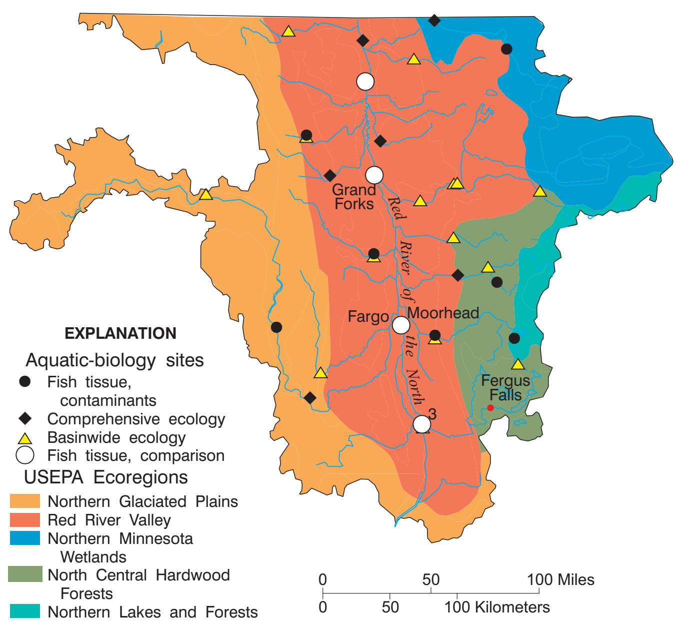


Table 5. Summary of data collected in the Red River of the North Basin reflects the multidisciplinary approach of NAWQA

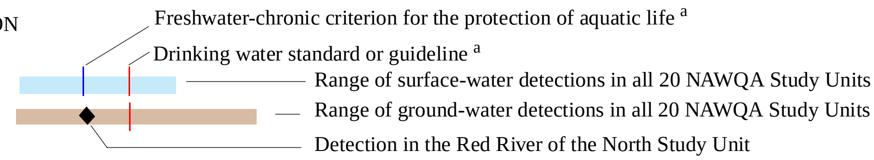
Study component	What data were collected and why	Types of sites sampled and water-quality measures	Number of sites or studies	Sampling frequency [period]
Ground-Water Quality				
Basinwide survey - surficial aquifers	Describe overall water quality in surficial sand and gravel aquifers which are susceptible to contamination.	Sample 20–30 wells in three of the major subregions for major ions, nutrients, pesticides, organic carbon, and radionuclides.	69	1
Basinwide survey - buried aquifers	Describe the overall water quality and natural chemical patterns in buried aquifers.	Sample wells within a west-east area across the central part of the Study Unit for major ions and trace elements; nutrients and radionuclides collected from 27 wells.	42	1
Land-use effects	Determine the effects of specific land use on the quality of shallow ground water.	For two surficial aquifers lying mostly beneath irrigated cropland, sample wells completed near water table for major ions, nutrients, and pesticides; from one aquifer, sample for volatile-organic compounds and radionuclides.	58	1
Seasonal variations	Determine seasonal variation of concentrations of water-quality indicators in aquifers studied for land-use effects.	Resample selected wells in each aquifer studied for land-use effects for nutrients, major ions, and organic carbon.	16	4-5 per year, [1994–95]
Variations along flow	Describe land-use effects on surficial aquifers along ground-water flow from areas of recharge beneath the land use to area of discharge to a stream.	Sample clusters of wells installed along an approximate line of ground-water flow and at various depths within aquifers studied for land-use effects; analyze for major ions, nutrients, pesticides, and age-dating constituents.	19	1
Stream-Water Quality				
Bed-sediment survey	Determine presence of potentially toxic compounds attached to sediments in major streams.	Sample depositional zones of the Red River and selected tributaries for trace elements, PAHs, and organochlorine compounds.	22	1 [1992]
Bed-sediment distribution survey	Determine distribution of toxic compounds attached to sediment in streams.	Sample sites in addition to bed-sediment survey sites mostly for trace elements.	8	1
Basinwide stream-chemistry sites	Describe concentrations and loads of chemicals, suspended sediment, and nutrients at selected sites basinwide.	Sample for major ions, organic carbon, suspended sediment, and nutrients at or near sites where streamflow is measured continuously.	15	~14 per year, [1993–95]
Intensive agriculture sites	Determine concentration and timing of agriculture related compounds that are transported to streams.	Subset of basinwide stream-chemistry sites where 80 pesticides are sampled at least monthly and during selected runoff events.	5	~20 per year, [1993–95]
Synoptic studies	Describe short-term presence and distribution of contamination over broad areas and how well the stream-chemistry stations represent the entire Red River Basin.	Sample streams during high flow for pesticides and (or) nutrients, suspended sediment, organic carbon, and streamflow; one synoptic sampling for volatile organic compounds.	27	1
Stream sediment	Describe the role of suspended sediment in transporting nutrients in streams.	Map stream-channel geometry and collect sediment samples during spring runoff and storm flows at selected sites along the Pembina River.	1	12
Aquatic Biology				
Fish tissues, contaminants	Determine presence of contaminants that can accumulate in fish tissues.	Collect fish species that live in most streams of the Study Unit; sample composites of whole fish for organic compounds and fish livers for trace elements.	11	1 [1992]
Comprehensive ecology	Assess in detail biological communities and habitat in streams representing primary ecological regions.	Sample and quantify fish, macroinvertebrates, and algae in four of the major ecological regions located at or near a basinwide stream chemistry site; quantitatively describe stream habitat for these organisms; replicate sampling for three consecutive years over three stream reaches.	6	1 per year, [1993–95]
Basinwide ecology	Determine presence and community structure of aquatic species and habitat in representative streams across the Study Unit.	Sample and identify fish, macroinvertebrates and algae at or near stream-chemistry sites and describe habitat.	16	1
Fish tissues, comparison	Determine differences in concentrations of mercury in different fish tissues in the Red River.	Sample two sizes of carp at four sites and catfish at one site in the Red River for mercury concentration in livers, fillets, and whole bodies.	4	1

The following tables summarize data collected for NAWQA studies from 1992–95 by showing results for the Red River Basin Study Unit compared to the NAWQA national range for each compound detected. The data were collected at a wide variety of places and times. In order to represent the wide concentration ranges observed among Study Units, logarithmic scales are used to emphasize the general magnitude of concentrations (such as 10, 100, or 1000), rather than the precise number. The complete dataset used to construct these tables is available upon request. The statistics for detection rates reported in Table 6 can differ from those reported in Figure 7 because of differing definitions of detection limits.

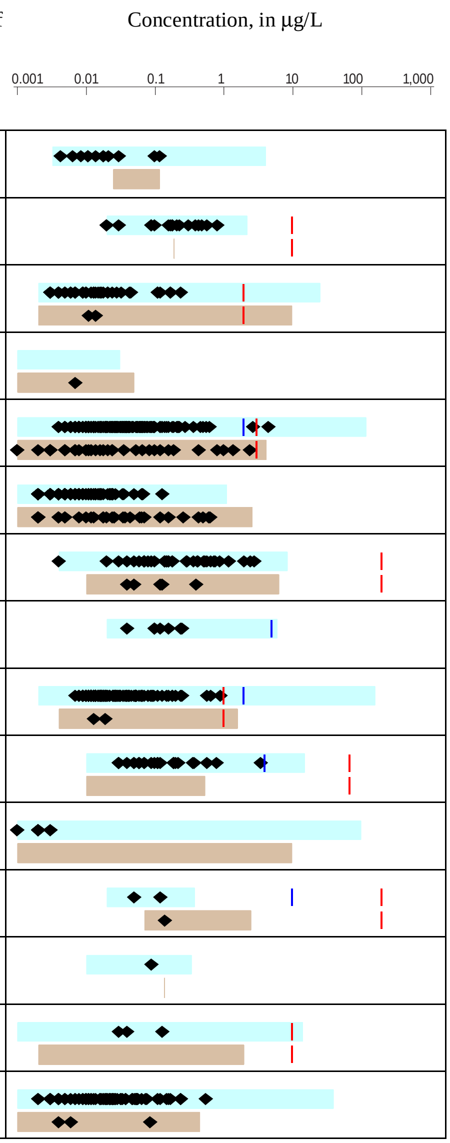
Table 6. Concentrations of herbicides, insecticides, volatile organic compounds, nutrients, and radon detected in surface or ground water of the Red River of the North Basin Study Unit

[mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; %, percent; <, less than;--, not measured; trade names may vary; footnotes on p. 29]

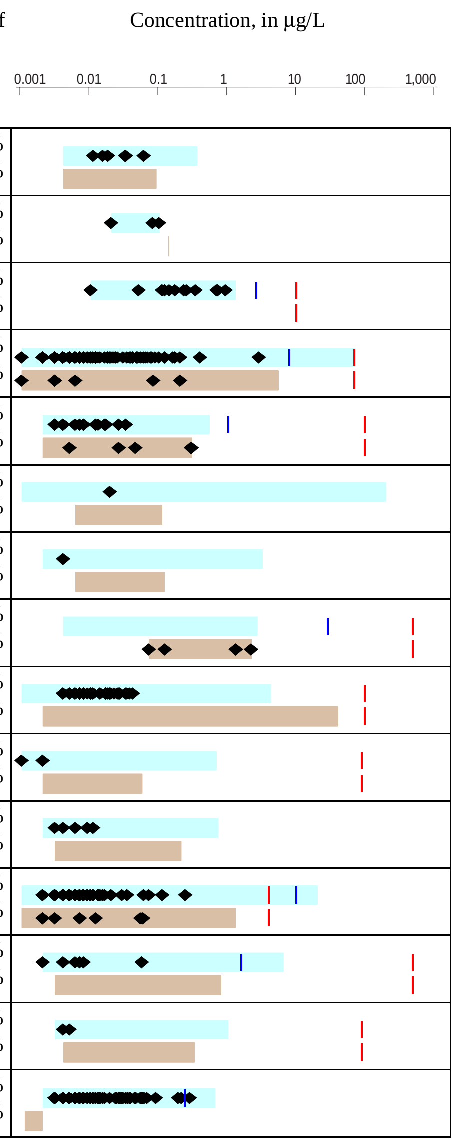
EXPLANATION



Herbicide (Trade or common name)	Rate of detection [b]
Acetochlor	12% 0%
Acifluorfen (Blazer)	9% 0%
Alachlor (Lasso)	11% 1%
2,6-Diethylaniline (metabolite)	0% <1%
Atrazine (AAtrex)	79% 16%
Desethylatrazine[c] (metabolite)	22% 15%
Bentazon (Basagran)	20% 3%
Bromoxynil (Buctril)	3% 0%
Cyanazine (Bladex)	56% 1%
2,4-D (Butyrac)	12% 0%
DCPA (Dacthal)	<1% 0%
Dicamba (Banvel)	1% 1%
Dichlorprop (Kildip)	<1% 0%
Diuron (Karmex, Direx)	1% 0%
EPTC (Eptam)	28% 1%



Herbicide (Trade or common name)	Rate of detection [b]
Ethalfluralin (Sonalan)	3% 0%
Fenuron (Beet-Kleen, fenidim)	1% 0%
MCPA	6% 0%
Metolachlor (Dual)	25% 1%
Metribuzin (Lexone, Sencor)	3% 3%
Molinate (Ordram)	<1% 0%
Pendimethalin (Prowl)	<1% 0%
Picloram (Tordon)	0% 3%
Prometon (Pramitol)	14% 0%
Propachlor (Ramrod)	<1% 0%
Propanil (Stampede)	<1% 0%
Simazine (Princep, Weedex)	10% 3%
Tebuthiuron (Spike)	<1% 0%
Terbacil[c] (Sinbar)	<1% 0%
Triallate (Far-Go)	19% 0%



Herbicide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L (0.001, 0.01, 0.1, 1, 10, 100, 1,000)
Trifluralin (Treflan)	7% 0%	

Insecticide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L (0.001, 0.01, 0.1, 1, 10, 100, 1,000)
Aldicarb[c] (Temik)	<1% 0%	
Azinphos-methyl[c] (Guthion)	<1% 0%	
Carbaryl[c] (Sevin, Savit)	<1% 0%	
Carbofuran[c] (Furadan)	14% 0%	
Chlorpyrifos (Lorsban)	2% 0%	
p,p'-DDE (metabolite)	<1% <1%	
Diazinon	<1% 0%	
Fonofos (Dyfonate)	1% 0%	
gamma-HCH	2% 0%	
Malathion (malathon, Cythion)	1% <1%	
Methyl parathion (Penncap-M)	<1% 0%	
Propoxur (Blatanex, Undene)	1% 0%	

Volatile organic compound (Trade or common name)	Rate of detection [b]	Concentration, in µg/L (0.01, 0.1, 1, 10, 100, 1,000)
1,2,4-Trimethylbenzene	-- 3%	
1,3,5-Trimethylbenzene	-- 3%	

Volatile organic compound (Trade or common name)	Rate of detection [b]	Concentration, in µg/L (0.01, 0.1, 1, 10, 100, 1,000)
Chloroethene (vinyl chloride)	-- 3%	
Dimethylbenzenes (total xylenes)	-- 3%	
Ethenylbenzene (styrene)	-- 3%	
Ethylbenzene (phenylethane)	-- 3%	
Isopropylbenzene (cumene)	-- 3%	
Methylbenzene (toluene)	-- 3%	
Naphthalene	-- 3%	
n-Butylbenzene (1-phenylbutane)	-- 3%	
n-Propylbenzene (isocumene)	-- 3%	

Nutrient	Rate of detection [b]	Concentration, in mg/L (0.01, 0.1, 1, 10, 100, 1,000, 10,000, 100,000)
Dissolved ammonia as nitrogen	92% 80%	
Dissolved ammonia plus organic nitrogen as nitrogen	100% 46%	
Dissolved phosphorus as phosphorus	90% 57%	
Dissolved nitrite plus nitrate as nitrogen	76% 54%	

Other	Rate of detection [b]	Concentration, in pCi/L (1, 10, 100, 1,000, 10,000, 100,000)
Radon 222	-- 99%	

Table 7. Herbicides, insecticides, volatile organic compounds, and nutrients not detected in surface or ground water of the Red River of the North Basin Study Unit

Herbicides

2,4,5-T

2,4,5-TP (Silvex, Fenoprop)

2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone)

Benfluralin (Balan, Benefin, Bonalan, Benefex)

Bromacil (Hyvar X, Urox B, Bromax)

Butylate (Sutan +, Genate Plus, Butilate)

Chloramben (Amiben, Amilon-WP, Vegiben)

Clopyralid (Stinger, Lontrel, Reclaim, Transline)

Dacthal mono-acid (Dacthal metabolite)

Dinoseb (Dinosebe)

Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon)

Linuron (Lorox, Linex, Sarclex, Linurex, Afalon)

MCPB (Thistrol)

Napropamide (Devrinol)

Neburon (Neburea, Neburyl, Noruben)

Norflurazon (Evital, Predict, Solicam, Zorial)

Oryzalin (Surflan, Dirimal)

Pebulate (Tillam, PEBC)

Pronamide (Kerb, Propyzamid)

Propham (Tuberite)

Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish)

Triclopyr (Garlon, Grandstand, Redeem, Remedy)

Insecticides

3-Hydroxycarbofuran (Carbofuran metabolite)

Aldicarb sulfone (Standak, aldoxycarb, aldicarb metabolite)

Aldicarb sulfoxide (Aldicarb metabolite)

Dieldrin (Panoram D-31, Octalox, Compound 497, Aldrin epoxide)

Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton)

Ethoprop (Mocap, Ethoprophos)

Methiocarb (Slug-Geta, Grandslam, Mesurol)

Methomyl (Lanox, Lannate, Acinate)

Oxamyl (Vydate L, Pratt)

Parathion (Roethyl-P, Alkron, Panthion, Phoskil)

Phorate (Thimet, Granutox, Geomet, Rampart)

Propargite (Comite, Omite, Ornamite)

Terbufos (Contraven, Counter, Pilarfox)

alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

cis-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

Volatile organic compounds

1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA)

1,1,1-Trichloroethane (Methylchloroform)

1,1,2,2-Tetrachloroethane

1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113)

1,1,2-Trichloroethane (Vinyl trichloride)

1,1-Dichloroethane (Ethylidene dichloride)

1,1-Dichloroethene (Vinylidene chloride)

1,1-Dichloropropene

1,2,3-Trichlorobenzene (1,2,3-TCB)

1,2,3-Trichloropropane (Allyl trichloride)

1,2,4-Trichlorobenzene

1,2-Dibromo-3-chloropropane (DBCP, Nemagon)

1,2-Dibromoethane (EDB, Ethylene dibromide)

1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB)

1,2-Dichloroethane (Ethylene dichloride)

1,2-Dichloropropane (Propylene dichloride)

1,3-Dichlorobenzene (*m*-Dichlorobenzene)

1,3-Dichloropropane (Trimethylene dichloride)

1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)

1-Chloro-2-methylbenzene (*o*-Chlorotoluene)

1-Chloro-4-methylbenzene (*p*-Chlorotoluene)

2,2-Dichloropropane

Benzene

Bromobenzene (Phenyl bromide)

Bromochloromethane (Methylene chlorobromide)

Bromomethane (Methyl bromide)

Chlorobenzene (Monochlorobenzene)

Chloroethane (Ethyl chloride)

Chloromethane (Methyl chloride)

Dibromomethane (Methylene dibromide)

Dichlorodifluoromethane (CFC 12, Freon 12)

Dichloromethane (Methylene chloride)

Hexachlorobutadiene

Methyl *tert*-butyl ether[d] (MTBE)

Tetrachloroethene (Perchloroethene)

Tetrachloromethane (Carbon tetrachloride)

Total Trihalomethanes (Trichloromethane (Chloroform), Dibromochloromethane, Bromodichloromethane, Tribromomethane (Bromoform))

Trichloroethene (TCE)

Trichlorofluoromethane (CFC 11, Freon 11)

cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)

cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)

p-Isopropyltoluene (*p*-Cymene)

sec-Butylbenzene

tert-Butylbenzene

trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)

trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)

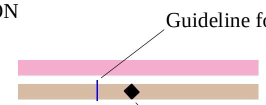
Nutrients

No non-detects

Table 8. Concentrations of semivolatile organic compounds, organochlorine compounds, and trace elements detected in fish tissue or bed sediment of the Red River of the North Basin Study Unit

[µg/g, micrograms per gram; µg/kg, micrograms per kilogram; %, percent;<, less than; - -, not measured; trade names may vary; footnotes on p. 29]

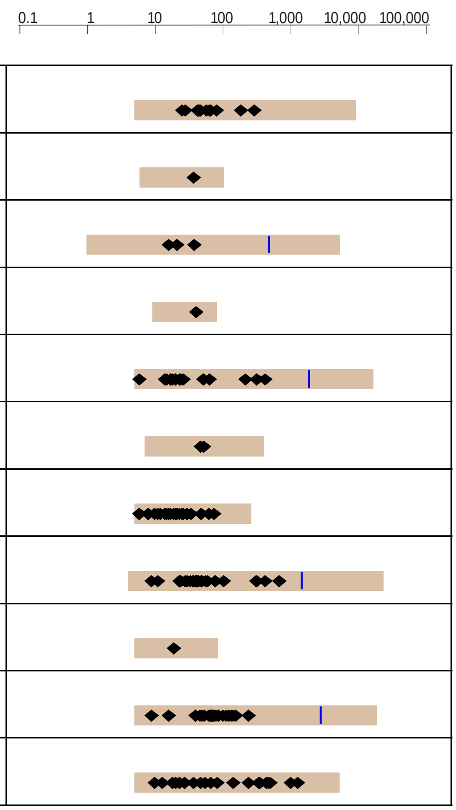
EXPLANATION



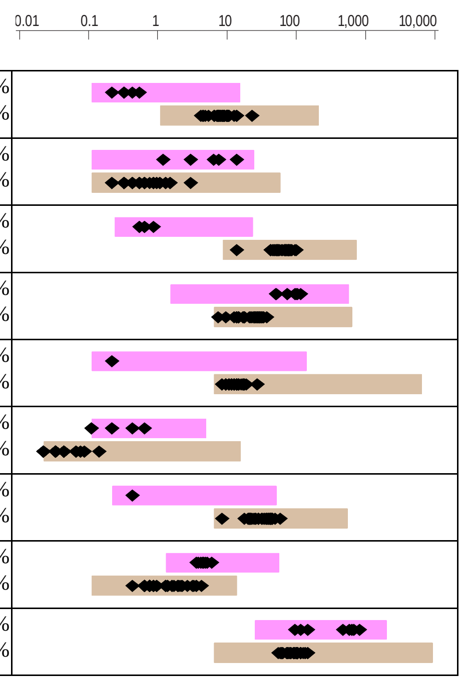
Semivolatile organic compound	Rate of detection [b]	Concentration, in µg/kg (0.1, 1, 10, 100, 1,000, 10,000, 100,000)
1,2-Dimethylnaphthalene	-- 14%	
1,6-Dimethylnaphthalene	-- 22%	
1-Methyl-9H-fluorene	-- 14%	
1-Methylphenanthrene	-- 31%	
1-Methylpyrene	-- 33%	
2,2-Biquinoline	-- 6%	
2,3,6-Trimethylnaphthalene	-- 14%	
2,6-Dimethylnaphthalene	-- 47%	
2-Ethylnaphthalene	-- 19%	
2-Methylanthracene	-- 22%	
3,5-Dimethylphenol	-- 6%	
4,5-Methylenephenanthrene	-- 25%	
4-Chloro-3-methylphenol	-- 3%	
9H-Carbazole	-- 44%	
9H-Fluorene	-- 44%	
Acenaphthene	-- 22%	
Acenaphthylene	-- 22%	

Semivolatile organic compound	Rate of detection [b]	Concentration, in µg/kg (0.1, 1, 10, 100, 1,000, 10,000, 100,000)
Acridine	-- 6%	
Anthracene	-- 47%	
Anthraquinone	-- 42%	
Benz[*a*]anthracene	-- 42%	
Benzo[*a*]pyrene	-- 42%	
Benzo[*b*]fluoranthene	-- 61%	
Benzo[*ghi*]perylene	-- 17%	
Benzo[*k*]fluoranthene	-- 64%	
Butylbenzylphthalate	-- 83%	
Chrysene	-- 53%	
Di- *n* -butylphthalate	-- 97%	
Di- *n* -octylphthalate	-- 17%	
Dibenz[*a,h*]anthracene	-- 14%	
Dibenzothiophene	-- 28%	
Diethylphthalate	-- 81%	
Dimethylphthalate	-- 6%	
Fluoranthene	-- 83%	

Semivolatile organic compound	Rate of detection [b]
Indeno[1,2,3-*cd*]pyrene	-- 39%
Isoquinoline	-- 3%
Naphthalene	-- 8%
N-Nitroso-diphenylamine	-- 3%
Phenanthrene	-- 53%
Phenanthridine	-- 6%
Phenol	-- 81%
Pyrene	-- 86%
Quinoline	-- 3%
bis(2-Ethyl-hexyl)phthalate	-- 92%
p-Cresol	-- 64%



Trace element	Rate of detection [b]
Arsenic	62% 100%
Cadmium	62% 98%
Chromium	62% 100%
Copper	100% 100%
Lead	13% 100%
Mercury	86% 88%
Nickel	13% 100%
Selenium	100% 100%
Zinc	100% 100%



Organochlorine compound	Rate of detection [b]
total-Chlordane	9% 0%
p,p'-DDE	73% 19%
total-DDT	73% 22%
PCB, total	36% 0%

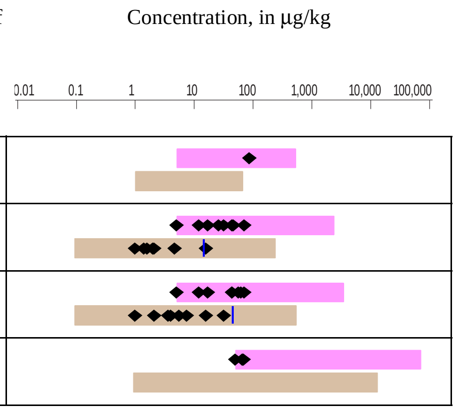


Table 9. Semivolatile organic compounds, organochlorine compounds, and trace elements not detected in fish tissue or bed sediment of the Red River of the North Basin Study Unit

Semivolatile organic compounds

1,2,4-Trichlorobenzene

1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB)

1,3-Dichlorobenzene (*m*-Dichlorobenzene)

1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)

2,3,5,6-Tetramethylphenol

2,4,6-Trichlorophenol

2,4,6-Trimethylphenol

2,4-Dichlorophenol

2,4-Dinitrophenol

2,4-Dinitrotoluene

2,6-Dinitrotoluene

2-Chloronaphthalene

2-Chlorophenol

2-Nitrophenol

4,6-Dinitro-2-methylphenol

4-Bromophenyl-phenylether

4-Chlorophenyl-phenylether

4-Nitrophenol

Azobenzene

Benzo [*c*] cinnoline

C8-Alkylphenol

Hexachlorobutadiene

Hexachlorocyclopentadiene

Hexachloroethane

Isophorone

N-Nitrosodi-*n*-propylamine

Nitrobenzene

Pentachloronitrobenzene

bis (2-Chloroethoxy)methane

bis (2-Chloroisopropyl)ether

Organochlorine compounds

Aldrin (HHDN, Octalene)

Chloroneb (chloronebe, Demosan, Soil Fungicide 1823)

DCPA (Dacthal, chlorthal-dimethyl)

Dieldrin (Panoram D-31, Octalox, Compound 497, Aldrin epoxide)

Endosulfan I (*alpha*-Endosulfan, Thiodan, Cyclodan, Beosit, Malix, Thimul, Thifor)

Endrin (Endrine)

Heptachlor epoxide (Heptachlor metabolite)

Heptachlor (Heptachlore, Velsicol 104)

Hexachlorobenzene (HCB)

Isodrin (Isodrine, Compound 711)

Mirex (Dechlorane)

Pentachloroanisole (PCA, pentachlorophenol metabolite)

Total Trihalomethanes (Trichloromethane (Chloroform), Dibromochloromethane, Bromodichloromethane, Tribromomethane (Bromoform))

Toxaphene (Camphechlor, Hercules 3956)

alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

beta-HCH (*beta*-BHC, *beta*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

cis-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

delta-HCH (*delta*-BHC, *delta*-hexachlorocyclohexane, *delta*-benzene hexachloride)

gamma-HCH (Lindane, *gamma*-BHC, Gammexane, Gexane, Soprocide, *gamma*-hexachlorocyclohexane, *gamma*-benzene hexachloride, *gamma*-benzene)

o,p'-Methoxychlor

p,p'-Methoxychlor (Marlate, methoxychlore)

trans-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

Trace elements

No non-detects

---

[a] Selected water-quality standards and guidelines (Gilliom and others, in press).

[b] Rates of detection are based on the number of analyses and detections in the Study Unit, not on national data. Rates of detection for herbicides and insecticides were computed by only counting detections equal to or greater than 0.01 µg/L in order to facilitate equal comparisons among compounds, which had widely varying detection limits. For herbicides and insecticides, a detection rate of "<1%" means that all detections are less than 0.01 µg/L, or the detection rate rounds to less than one percent. For other compound groups, all detections were counted and minimum detection limits for most compounds were similar to the lower end of the national ranges shown. Method detection limits for all compounds in these tables are summarized in Gilliom and others (in press).

[c] Detections of these compounds are reliable, but concentrations are determined with greater uncertainty than for the other compounds and are reported as estimated values (Zaugg and others, 1995).

[d] The guideline for methyl *tert*-butyl ether is between 20 and 40 µg/L; if the tentative cancer classification C is accepted, the lifetime health advisory will be 20 µg/L (Gilliom and others, in press).

[e] Selected sediment-quality guidelines (Gilliom and others, in press).

Brigham, M.E., Goldstein, R.M., and Tornes, L.H., 1998, Trace elements and organic chemicals in stream-bottom sediments and fish tissues, Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1992–95: U.S. Geological Survey Water-Resources Investigations Report 97–4043, 32 p.

Brigham, M.E., Mayer, Tatiana, McCullough, G.K., and Tornes, L.H., 1996, Transport and speciation of nutrients in tributaries to souther Lake Winnipeg, Canada: North American Lake Management Society, 16th Annual International Symposium—Final Program, November 13–16, 1996, p. 64.

Brunskill, G.J., Elliott, S.E.M., and Campbell, P., 1980, Morphometry, hydrology, and watershed data pertinent to the limnology of Lake Winnipeg: Canadian Manuscript Report of Fisheries and Aquatic Sciences 1556, 32 p.

Canadian Council of Ministers of the Environment, 1992, Canadian water quality guidelines, Appendix XI—updates (April 1992): Ottawa, Ontario, Task Force on Water Quality Guidelines of the Canadian Council of Ministers of the Environment, variously paged.

Cowdery, T.K., 1995, Similar agricultural areas, different ground-water quality—Red River of the North Basin, 1993–95: U.S. Geological Survey Open-File Report 95–441, 4 p.

Cowdery, T.K., 1997, Shallow ground-water quality beneath cropland in the Red River of the North Basin, Minnesota and North Dakota, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 97–4001, 52 p.

Cowdery, T.K., in press, Ground-water quality in the Red River of the North Basin, Minnesota and North Dakota, 1993–95: U.S. Geological Survey Water-Resources Investigations Report

Cowdery, T.K., and Brigham, M.E., 1992, Baseflow dissolved-solids loads to streams of the Red River of the North basin, South Dakota, North Dakota, and Minnesota: 37th Annual Midwest Ground Water Conference Program with Abstracts, October 14–16, 1992, Sioux Falls, South Dakota, p. 38.

Cowdery, T.K., and Goff, K.L., 1994, Nitrogen concentrations near the water table of the Sheyenne Delta aquifer beneath cropland areas, Ransom and Richland Counties, North Dakota: North Dakota Water Quality Symposium Proceedings, March 30–31, 1994, Fargo, North Dakota, North Dakota State University Extension Service, p. 89–102.

Cowdery, T.K., and Saylor, K.N., 1996, Contrasting water quality of two surficial aquifers in the Red River of the North drainage basin, North Dakota and Minnesota: North Dakota Water Quality Symposium Proceedings, March 20–21, 1996, Bismarck, North Dakota, North Dakota State University Extension Service, p. 146; also in Minnesota Water ‘96 collection of conference abstracts, May 20–21, 1996, Minneapolis, Minnesota, University of Minnesota Water Resources Research Center, p. 98.

Cowdery, T.K., Stoner, J.D., and Lorenz, D.L., 1995, Distribution and movement of nitrate in a surficial outwash aquifer beneath irrigated cropland, northwestern Minnesota: American Geophysical Union, EOS Transactions, Abstracts for Fall Meeting—December 11–15, 1995, p. 195.

Gilliom, R.J., Mueller, D.K, and Nowell, L.H., in press, Methods for comparing water-quality conditions among National Water-Quality Assessment Study Units, 1992–95: U.S. Geological Survey Open-File Report 97–589.

Goldstein, R.M., 1995, Aquatic communities and contaminants in fish from streams of the Red River of the North Basin, Minnesota and North Dakota: U.S. Geological Survey Water-Resources Investigations Report 95–4047, 34 p.

Goldstein, R.M., Brigham, M.E., and Stauffer, 1996a, Comparison of mercury concentrations in liver, muscle, whole bodies, and composites of fish from the Red River of the North: Canadian Journal of Fisheries and Aquatic Sciences, v. 53, no. 2, p. 244–252.

Goldstein, R.M., Simon, T.P, Bailey, P.A., Ell, Michael, Pearson, Eric, Schmidt, Konrad, and Enblom, J.W., 1994, Concepts for an index of biotic integrity for streams of the Red River of the North Basin: North Dakota Water Quality Symposium Proceedings, March 30–31, 1994, Fargo, North Dakota, North Dakota State University Extension Service, p. 169–180.

Goldstein, R.M., Stauffer, J.C., Larson, P.R., and Lorenz, D.L., 1996b, Relation of physical and chemical characteristics of streams to fish communities in the Red River of the North Basin, Minnesota and North Dakota, 1993–95: Water-Resources Investigations Report 96–4227, 57 p.

Goodbred, S.L., Gilliom, R.J., Gross, T.S., Denslow, N.P., Bryant, W.B., and Schoeb, T.R., 1997, Reconnaissance of 17β-estradiol, 11-ketotestosterone, vitellogenin, and gonad histopathology in common carp of the United States streams—Potential for contaminant-induced endocrine distruption: U.S. Geological Survey Open-File Report 96–627, 47 p.

Lorenz, D.L. and Stoner, J.D., 1996, Sampling design for assessing water quality in the Red River of the North Basin, North Dakota, South Dakota, and Minnesota, 1993–95: U.S. Geological Survey Water-Resource Investigations Report 96–4129, 2 plates.

Menheer, M.A., and Brigham, M.E., 1997, Ground-water sampling methods and quality-control data for the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 96–4317, 34 p.

Minnesota Department of Natural Resources, 1994, Minnesota fish contaminant monitoring program, 1990–1992 data document: Minnesota Department of Natural Resources 81 p.

Nielsen, E., McLeod, K.D., Pip, E., and Doering, J.C., 1996, Late Holocene environmental changes in southern Manitoba—Field trip guidebook A2: Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27–29, 33 p.

Niemela, Scott, Pearson, Eric, Simon, T.P., Goldstein, R.M., and Bailey, P.A., in press, Development of index of biotic integrity expectations for the Lake Agassiz Plain Ecoregion: U.S. Environmental Protection Agency report EPA 905/R-96–005.

Omernik, J.M., 1987, Ecoregions of the United States: Annals of the Association of American Geographers, vol. 77, p. 118–125.

Puckett, L.J., Tornes, L.H., Cowdery, T.K., Brigham, M.E., and Stoner, J.D., 1995, The role of wetlands in reducing nitrogen loadings to the Otter Tail River in Minnesota: American Geophysical Union, EOS Transactions, Abstracts for Fall Meeting—December 11–15, 1995, p. 186.

Stauffer, J.C., and Goldstein, R.M., 1997, Comparison of three qualitative habitat indices and their applicability to prairie streams: North American Journal of Fisheries Management, v. 17, no. 2, p. 348–61.

Stoner, J.D., Cowdery, T.K., and Puckett, L.J.,1997, Ground water age dating and other tools to assess land-use effects on water quality: U.S. Geological Survey Water-Resources Investigations Report 97–4150, 6 p.

Stoner, J.D., and Lorenz, D.L., 1995, National Water-Quality Assessment Program—Data collection in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1992–95: U.S. Geological Survey Fact Sheet FS-172–95, 4 p.

Stoner, J.D., Lorenz, D.L., Wiche, G.J., and Goldstein, R.M., 1993, Red River of the North Basin, Minnesota, North Dakota, and South Dakota: American Water Resources Association Monograph Series No. 19 and Water Resources Bulletin, v. 29, no. 4, p. 575–615.

Strobel, M.L., and Gerla, P.J., 1992, Effects of saline ground-water discharge on water quality in the Red River of the North, northeastern North Dakota: Preliminary observations of the hydrologic setting—North Dakota Water Quality Symposium Proceedings, March 25–26 1992, Bismarck, North Dakota, p. 60–82.

Strobel, M.L., and Gerla, P.J., 1993, Hydrologic and anthropogenic influences on the occurrence of saline wetlands in the Red River of the North Valley, northeastern North Dakota—Prairie ecosystems: Abstracts, Wetlands Ecology, Management and Restoration, Wetland Symposium, August 9–13, 1993, Jamestown, North Dakota, p. 44.

Strobel, M.L., and Haffield, N.D., 1995, Salinity in surface water in the Red River of the North basin, northeastern North Dakota: U.S. Geological Survey Water-Resources Investigations Report 95–4082, 14 p.

Strobel. M.L., and Radig, S.A., 1997, Effects of the 1993 flood on water levels and water quality in the Sheyenne Delta aquifer, southeastern North Dakota, 1993–94: U.S. Geological Survey Water-Resources Investigations Report 97–4163, 43 p.

Strobel, M.L., Kelly, J.B., Carlson, S.T., and Salender, H.A., 1994, Flowing wells in northeastern North Dakota and their possible effect on water quality in the Red River of the North basin: North Dakota Water Quality Symposium Proceedings, March 30–31, 1994, Fargo, North Dakota, p. 247–255.

Tornes, L.H., and Brigham. M.E., 1994, Nutrients, suspended sediment, and pesticides in waters of the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1970–1990: U.S. Geological Survey Water-Resources Investigations Report 93–4231, 62 p.

Tornes, L.H., and Brigham, M.E., 1995, Pesticide amounts are small in streams of the Red River of the North Basin, 1993–94: U.S. Geological Survey Open-File Report 95–283, 2 p.

Tornes, L.H., Brigham, M.E., and Lorenz, D.L., 1997, Nutrients, suspended sediment, and pesticides in streams in the the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 97–4053, 70 p.

Tornes, L.H., Puckett, L.J., Porter, S.D., and Stoner, J.D., 1996, Variations of nitrate beneath a riparian wetland in Minnesota and its relation to stream biota: American Geophysical Union, EOS Transactions, Abstracts for Fall Meeting—December 11–15, 1995, p. 186.

Tornes, L.H., Puckett, L.J., Stoner, J.D., and Brigham, M.E., 1994, The effect of riparian wetlands in reducing nitrate-nitrogen from a sand and gravel aquifer to a stream: American Geophysical Union, EOS Transactions, Abstracts for Fall Meeting—December 5–9, 1994, p. 261.

U.S. Environmental Protection Agency, November 23, 1994, Atrazine, simazine, cyanazine—notice of initiation of special review: Federal Register, v. 59, p. 60412–60443.

Ware, G.W., ed., 1994, Reviews of environmental contamination and toxicology: New York, Springer-Verlag, v. 140, 221 p.

Waters, T.F., 1995, Sediment in streams—Sources, biological effects, and control: American Fisheries Society Monograph 7, Bethesda, Maryland, 251 p

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95–181, 49 p..

The terms in this glossary were compiled from numerous sources. Some definitions have been modified and may not be the only valid ones for these terms.

Algae - Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic, but some species can be as large as vascular plants.

Ammonia - A compound of nitrogen and hydrogen (NH_3) that is a common by-product of animal waste. Ammonia readily converts to nitrate in soils and streams.

Aquifer - A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Bed sediment - The material that temporarily is stationary in the bottom of a stream or other watercourse.

Concentration - The amount or mass of a substance present in a given volume or mass of sample. Usually expressed as microgram per liter (water sample) or micrograms per kilogram (sediment or tissue sample).

Constituent - A chemical or biological substance in water, sediment, or biota that can be measured by an analytical method.

Cubic foot per second (ft^3/s or cfs) - Rate of water discharge representing a volume of 1 cubic foot passing a given point during 1 second, equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.2832 cubic meter per second.

Denitrification - A process by which oxidized forms of nitrogen such as nitrate (NO_3^-) are reduced to form nitrites, nitrous oxides, ammonia, or free nitrogen: commonly brought about by the action of denitrifying bacteria and usually resulting in the escape of nitrogen to the air.

Discharge - Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

Dissolved solids - Amount of minerals, such as salt, that are dissolved in water; amount of dissolved solids is a indicator of salinity or hardness.

Drinking-water standard or guideline - A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Ecological studies - Studies of biological communities and habitat characteristics to evaluate the effects of physical and chemical characteristics of water and hydrologic conditions on aquatic biota and to determine how biological and habitat characteristics differ among environmental settings in the NAWQA Study Units.

Ecoregion - An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Ecosystem - The interacting populations of plants, animals, and micro-organisms occupying an area, plus their physical environment.

Eutrophication - The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Fungicide - A substance or mixture of substances intended to destroy or inhibit the growth of fungi.

Ground water - In general, any water that exists beneath the land surface, but more commonly applied to water in fully saturated soils and geologic formations.

Habitat - The part of the physical environment where plants and animals live.

Health advisory - Nonregulatory levels of contaminants in drinking water that may be used as guidance in the absence of regulatory limits. They consist of estimates of concentrations that would result in no known or anticipated health effects (for carcinogens, a specified cancer risk) determined for a child or for an adult for various exposure periods.

Herbicide - A chemical or other agent applied for the purpose of killing undesirable plants. *See also* Pesticide.

Index of Biotic Integrity (IBI) - An aggregated number, or index, based on several attributes or metrics of a fish community that provides an assessment of biological conditions.

Insecticide - A substance or mixture of substances intended to destroy or repel insects.

Load - General term that refers to a material or constituent in solution, suspension, or in transport; usually expressed in terms of mass or volume.

Maximum contaminant level (MCL) - Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Mean - The average of a set of observations, unless otherwise specified.

Median - The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

Method detection limit - The minimum concentration of a substance that can be accurately identified and measured with present laboratory technologies.

Micrograms per liter (μg/L) - A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

Milligrams per liter (mg/L) - A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

Nitrate - An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Nonpoint source - A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

Nutrient - Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Organochlorine insecticide - A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

Outwash - Soil material washed down a hillside by glacial meltwater and deposited upon more gently sloping land.

Part per million (ppm) - Unit of concentration equal to one milligram per kilogram or one milligram per liter.

Pesticide - A chemical applied to crops, rights-of-way, lawns or residences to control weeds, insects, fungi, nematodes, rodents or other "pests."

Phosphorus - A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Picocurie (pCi) - One trillionth (10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7×10^{10} radioactive disintegrations per second (dps). A picocurie yields 2.22 disintegrations per minute (dpm) or 0.037 dps.

Polychlorinated biphenyls (PCBs) - A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Polycyclic aromatic hydrocarbon (PAH) - A class of organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of unburned coal and oil. PAHs include benzo(a)pyrene, fluoranthene, and pyrene.

Radon - A naturally occurring, colorless, odorless, radioactive gas formed by the disintegration of the element radium; damaging to human lungs when inhaled.

Recharge - Water that infiltrates the ground and reaches the saturated zone.

Riparian - Areas adjacent to rivers and streams with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Secondary maximum contaminant level (SMCL) - The maximum contamination level in public water systems that, in the judgment of the U.S. Environmental Protection Agency (USEPA), are required to protect the public welfare. SMCLs are secondary (nonenforceable) drinking water regulations established by the USEPA for contaminants that may adversely affect the odor or appearance of such water.

Semivolatile organic compound (SVOC) - Operationally defined as a group of synthetic organic compounds that are solvent-extractable and can be determined by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, and polycyclic aromatic hydrocarbons (PAHs).

Shallow ground water - In this report, refers to water (generally, aged less than 10 years) that is within 10 feet below the water table.

Surficial aquifer - An aquifer located within close proximity to the land surface (as compared to locally deep ground-water aquifers) in which recently recharged ground water is commonly susceptible to contamination from activities on the land surface.

Suspended sediment - Particles of rock, sand, soil, and organic detritus carried in suspension in the water column, in contrast to sediment that moves on or near the streambed.

Trace element - An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

Volatile organic compounds (VOCs) - Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some by-products of chlorine disinfection.

Water-quality criteria - Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to water-quality criteria established by the U.S. Environmental Protection Agency. Water-quality criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

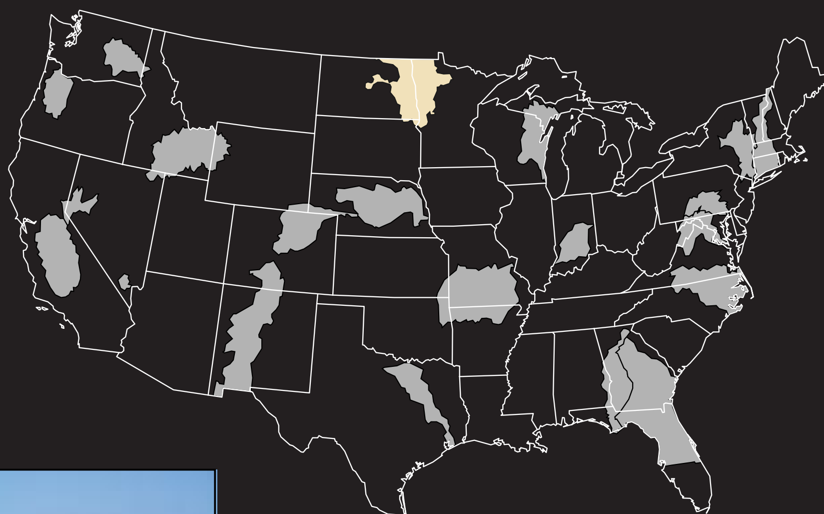
Water table - The point below the land surface where ground water is first encountered and below which the earth is saturated. Depth to the water table varies widely across the country.

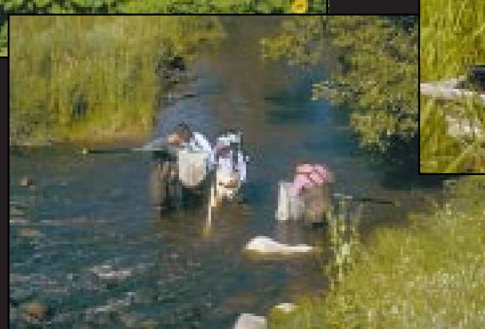
Wetlands - Ecosystems whose soil is saturated for long periods seasonally or continuously, including marshes, swamps, and ephemeral ponds.

Yield - The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

NAWQA

National Water-Quality Assessment (NAWQA) Program
Red River of the North





Stoner and others • Water Quality in the Red River of the North
USGS Circular 1169 • 1998

ISBN 0-607-89117-3
9 780607 891171