Sampling-Site Stratification and Design—continued

For the study of aquatic organisms, the proposed framework is insufficient because aquatic organisms are more sensitive to the local stream-reach habitat than to basin-wide characteristics. Many of the ecological sampling sites were selected primarily on the basis of an ecoregions framework (figs. 5 and 6). Wherever feasible, sampling sites for water, sediment, and aquatic organisms were co-located on streams in order to assess water-quality conditions using a variety of indicators.

The environmental framework characteristics are summarized in tables 2 and 3 and the resulting sampling-site stratification is shown in the right-most column of these tables. For each stream site in table 2, the drainage area percentage is shown for each subdivision of the environmental framework; (1) physiography, (2) soil drainage and texture, and (3) major land cover and land use, and crops. Any category comprising more that 50 percent of the drainage area for the sampling site was considered the dominant category for the stratification. For those sites where all specific categories of a major landscape characteristic were less than 50 percent of the drainage area, the two categories with the largest combined area exceeding 66 percent of the drainage area were considered the dominant categories. For example, the dominant categories for the Turtle River at Turtle River State Park (map number 22) are Drift Prairie (72 percent), soil groups 1 and 2 (76 percent), and agriculture (96 percent); the sampling stratum is A2,1a. Although few of the indicator sites represent a single sampling stratum, some are reasonably close. Table 4 shows how the final sampling sites for streams and surficial aquifers in the Red River Basin study unit compare to the environmental framework (table 1).

For a few stream sites, the sampling reach (used for ecological sampling) may be affected by localized environmental conditions that are different than those represented by the environmental framework characteristics shown in table 2. In this situation, ecological sampling results can be influenced by local habitat factors more than by the quality of water from upstream. As an example, the Snake River above Alvarado, Minn. site (map no. 24) is located in sampling stratum B1a, but the drainage basin above this site reflects the B4a sampling stratum.

Hydrologic statistics are summarized in table 2 to indicate the long- and short-term character of streamflow and runoff for sampling sites. The hydrologic statistics can provide an indication of the volume and energy of water generally available to transport chemicals and sediment from the land to streams. Mean annual discharge and runoff were computed for 1947-94, a 47-year period in which data are available for many of the sites. For several of these sampling sites, mean annual statistics were estimated for 1947-94 based on streamflow records from nearby gaging stations on the same stream. Some sampling sites established for this study were on ungaged streams or were too far from existing gages to adequately estimate long-term flow statistics.

The long-term hydrologic data show how streamflow and runoff vary among physiographic areas. For example, the 1947-94 mean-annual runoff generally is less than 1 inch (in.) for sampling sites that have drainage basins that originate in the Drift Prairie. In contrast, mean-annual runoff for the same period is greater than 2.8 in. for sampling sites east of the Red River, which have drainage basins in the Moraine and Lake-Washed Till Plain.

Comparison of mean-annual runoff between the long term (1947-94) and the short-term (1993-94) shows that streamflow was above normal during the period of intensive sampling for stream chemistry and ecology in this study (table 2). The mean annual runoff during 1993-94 was twice the mean annual runoff than during 1947-94 for many sites. For all of the sampling sites having long-term streamflow data, the 1993-94 runoff exceeded the long-term runoff by an amount ranging from 4 percent (Red Lake River) to 301 percent (Bois de Sioux River). Figure 5 (inset) shows how the hydrologic regime in 1993-94 compared to the long term daily discharge for the Red River at Emerson, Manitoba gage. Samples collected during the summer months of 1993 and 1994 represented conditions of above-normal flow. These abnormally high summer streamflows occurred at other sampling sites throughout the Red River Basin study unit.

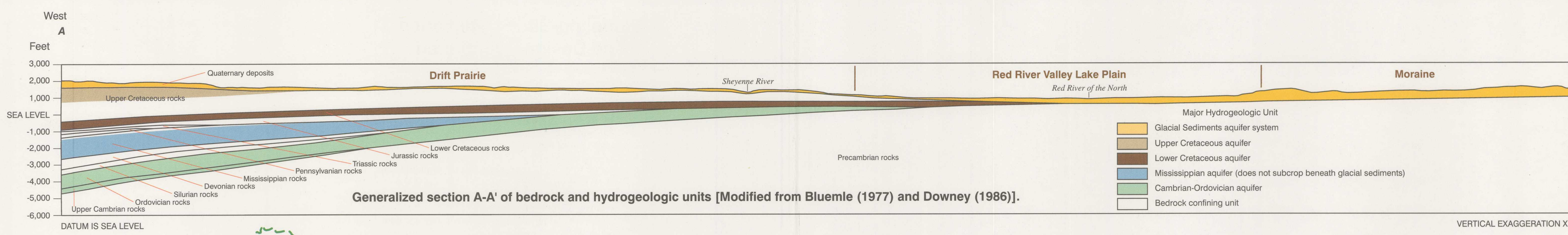
Other hydrologic statistics shown in table 2 can be particularly useful to evaluate the biological quality of study unit streams within the context of water-quality assessment. The 90th percent exceedence of mean daily flow approximates baseflow conditions. Sampling sites which have extremely low baseflow conditions (less than 2 cubic feet per second (ft^3/s)), such as sites 4, 7, 10, 15, 23, and 27 originate in the Drift Prairie. Baseflow at most sites in the Minnesota part of the study unit and the Red River downstream from the confluence with the Red Lake River exceeds 20 ft^3/s. These eastern sites also have the highest runoff among Red River Basin study unit sites. Low baseflow has a greater effect than water quality on the composition and population of aquatic organisms in streams (Poff and Allen, 1995). Furthermore, extremely low baseflow streams have a low capacity to assimilate potentially toxic contaminants. The variability of flow from year to year affects stream habitat and aquatic organisms. It is measured by the coefficient of variation of mean annual streamflow (table 2). Relatively large coefficients of variation (greater than 90 percent) occur for sampling sites that have a significant part of drainage from the Drift Prairie. The less variable year-to-year flows (coefficient of variation less than 54 percent) occur at sampling sites in Minnesota tributaries that have drainage-basin headwaters in the Moraine.

Drainage density (expressed as total river and drainage ditch length divided by the drainage area), can be used to approximate potential chemical and sediment delivery from land sources to streams. The smallest drainage densities for sampled basins were in the Red River Valley Lake Plain and the Drift Prairie (table 2). The largest drainage densities for sampled basins were in the Moraine.

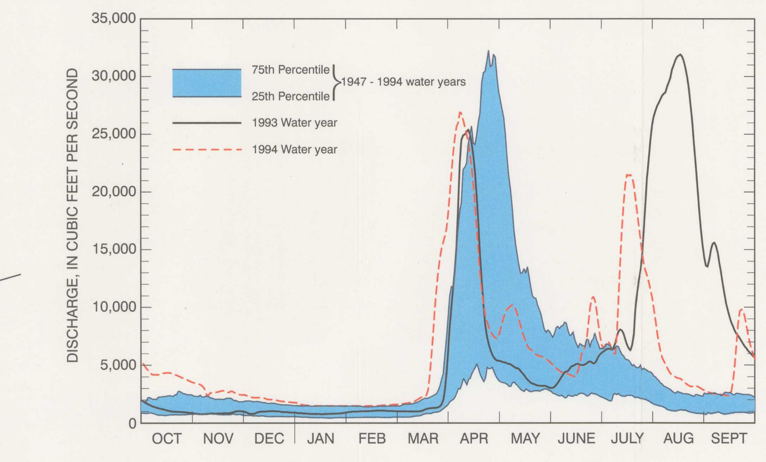
The sampling stratification also is shown for ground water (table 3). General land characteristics over the surficial aquifers are summarized according to sampling strata in each study component. These land characteristics do not reflect statistical summaries of soil groups and land cover or land use in specific recharge areas for each well sampled, but provide a good indication of land features typical for these well sites. The coarser-textured soils generally are located over these surficial aquifers. Also, the primary crops grown over the land-use-study areas (corn, hay, and beans) are not typical of major crops grown across the Red River Basin study unit, but are typical of relatively small areas in the southern part of the study unit. Subsurface sampling strata only are indicated for the buried aquifers studied.

Subsurface conditions, such as aquifer materials and residence time of ground water, also are important factors for assessing ground-water quality and for evaluating the effects of land-surface factors. Table 3 shows characteristics of aquifers relative to physiographic areas, the primary sampling stratification used for the this study. For surficial sand and gravel aquifers, the Moraine has the most transmissive and perhaps chemically inert aquifer materials. Surficial aquifers in the Drift Prairie have transmissive characters similar to the Moraine, but contain more calcareous materials. Surficial aquifers in the Red River Valley Lake Plain generally have finer grained materials, are the least transmissive in the study unit, and have a mixture of source materials. The Sheyenne Delta aquifer, representative of the Red River Valley Lake Plain, and the Otter Tail Outwash aquifer, representative of the Moraine, were selected for detailed assessment of land-use effects and to gain a better understanding of processes that affect ground-water quality. The range of reported hydraulic conductivities (a measure of permeability of the aquifer material) indicates that the Otter Tail Outwash aquifer can be more permeable than the Sheyenne Delta aquifer by 1 to 4 orders of magnitude. This range of hydraulic conductivity suggests that with similar conditions of hydraulic gradient and porosity, average seepage velocity, and the movement of contaminants potentially are greater for the Moraine aquifers than for Red River Valley Lake Plain aquifers.

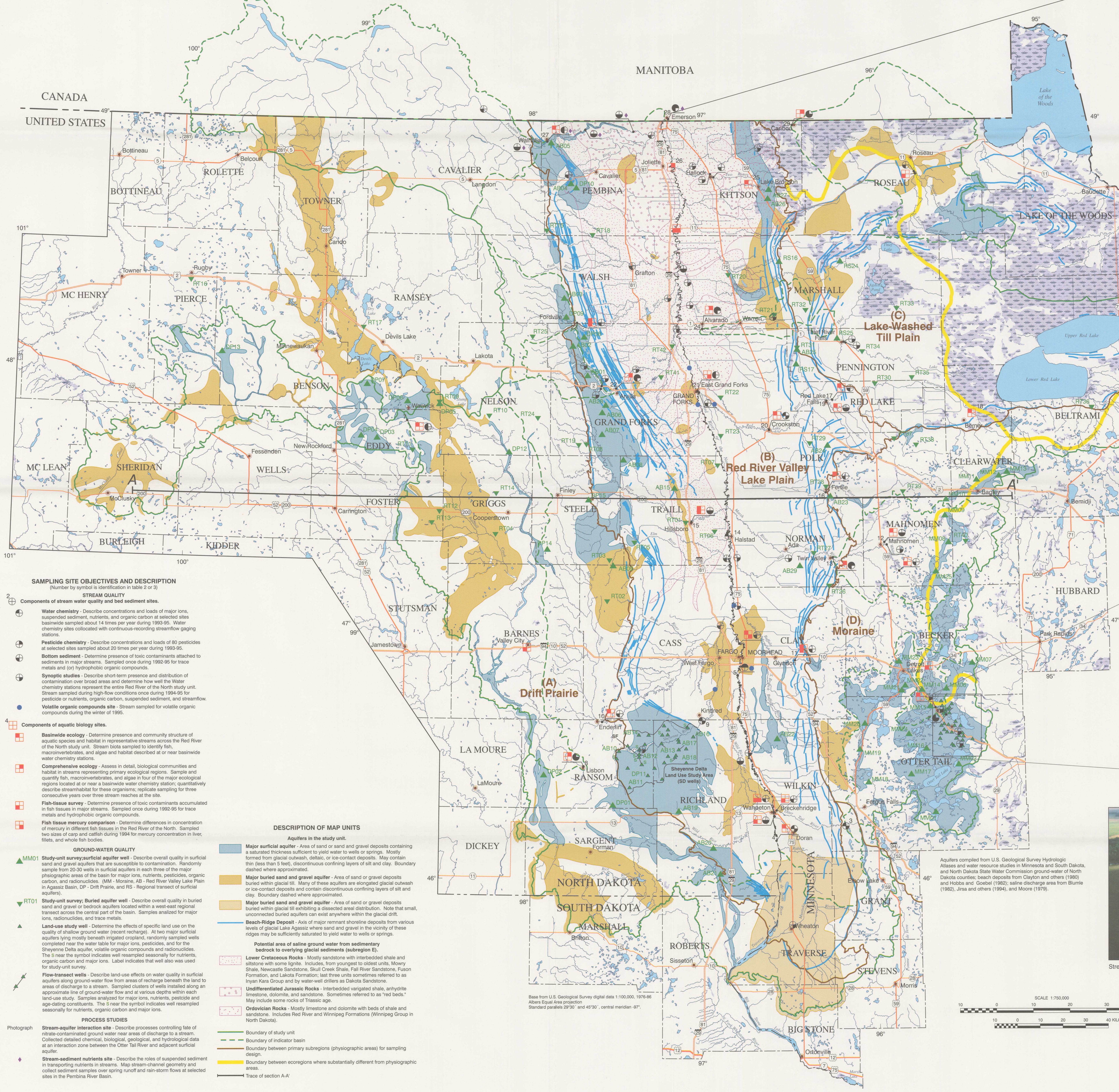
For assessing ground-water quality, an attempt was made to minimize factors that can confound the interpretation of well-water samples. The wells sampled were located according to random selection procedure for a given area of aquifer studied (Scott, 1990). Similar well type, well depth, screened interval, and water level were intentionally selected among the various sampling strata for surficial aquifers to provide for comparable results. Consistency in the screened interval of the well is particularly important because of the potential to withdraw water having a large range of ages in thick surficial aquifers, such as exist in the Red River Basin study unit. Unusually large recharge from rainfall shortly before the sampling period decreased the median depth to water for the Sheyenne Delta aquifer.



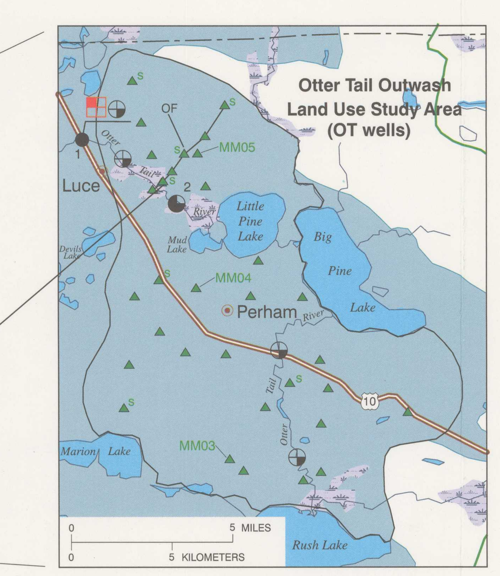
Generalized section A-A' of bedrock and hydrogeologic units [Modified from Bluemle (1977) and Downey (1986)].



Daily discharge at Red River at Emerson, Man.



Aquifers compiled from U.S. Geological Survey Hydrologic Atlases and water resource studies in Minnesota and South Dakota, and North Dakota State Water Commission ground-water studies of North Dakota counties; beach deposits from Clayton and others (1980) and Hobbs and Goebel (1982); saline discharge area from Bluemle (1982), Jirsa and others (1994), and Moore (1979).



SAMPLING SITE OBJECTIVES AND DESCRIPTION

(Number by symbol is identification in table 2 or 3)

STREAM QUALITY

Components of stream water quality and bed sediment sites.

Water chemistry - Describe concentrations and loads of major ions, suspended sediment, nutrients, and organic carbon at selected sites basinwide sampled about 14 times per year during 1993-95. Water chemistry sites collocated with continuous-recording streamflow gaging stations.

Pesticide chemistry - Describe concentrations and loads of 80 pesticides at selected sites sampled about 20 times per year during 1993-95.

Bottom sediment - Determine presence of toxic contaminants attached to sediments in major streams. Sampled once during 1992-95 for trace metals and (or) hydrophobic organic compounds.

Synoptic studies - Describe short-term presence and distribution of contamination over broad areas and determine how well the Water chemistry stations represent the entire Red River of the North study unit. Stream sampled during high-flow conditions once during 1994-95 for pesticide or nutrients, organic carbon, suspended sediment, and streamflow.

Volatile organic compounds site - Stream sampled for volatile organic compounds during the winter of 1995.

Components of aquatic biology sites.

Basinwide ecology - Determine presence and community structure of aquatic species and habitat in representative streams across the Red River of the North study unit. Stream biota sampled to identify fish, macroinvertebrates, and algae and habitat described at or near basinwide water chemistry stations.

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 water chemistry station; quantitatively describe streamhabitat for these organisms; replicate sampling for three consecutive years over three stream reaches at the site.

Fish-tissue survey - Determine presence of toxic contaminants accumulated in fish tissues in major streams. Sampled once during 1992-95 for trace metals and hydrophobic organic compounds.

Fish tissue mercury comparison - Determine differences in concentration of mercury in different fish tissues in the Red River of the North. Sampled two sizes of carp and catfish during 1994 for mercury concentration in liver, fillets, and whole fish bodies.

GROUND-WATER QUALITY

MM01 **Study-unit survey;surficial aquifer well** - Describe overall quality in surficial sand and gravel aquifers that are susceptible to contamination. Randomly sample from 20-30 wells in surficial aquifers in each three of the major phsiographic areas of the basin for major ions, nutrients, pesticides, organic carbon, and radionuclides. (MM - Moraine, AB - Red River Valley Lake Plain in Agassiz Basin, DP - Drift Prairie, and RS - Regional transect of surficial aquifers).

RT01 **Study-unit survey; Buried aquifer well** - Describe overall quality in buried sand and gravel or bedrock aquifers located within a west-east regional transect across the central part of the basin. Samples analized for major ions, radionuclides, and trace metals.

Land-use study well - Determine the effects of specific land use on the quality of shallow ground water (recent recharge). At two major surficial aquifers lying mostly beneath irrigated cropland, randomly sampled wells completed near the water table for major ions, pesticides, and for the Sheyenne Delta aquifer, volatile organic compounds and radionuclides. The S near the symbol indicates well resampled seasonally for nutrients, organic carbon and major ions. Label indicates that well also was used for study-unit survey.

Flow-transect wells - Describe land-use effects on water quality in surficial aquifers along ground-water flow from areas of recharge beneath the land to areas of discharge to a stream. Sampled clusters of wells installed along an approximate line of ground-water flow and at various depths within each land-use study. Samples analyzed for major ions, nutrients, pestcide and age-dating constituents. The S near the symbol indicates well resampled seasonally for nutrients, organic carbon and major ions.

PROCESS STUDIES

Photograph **Stream-aquifer interaction site** - Describe processes controlling fate of nitrate-contaminated ground water near areas of discharge to a stream. Collected detailed chemical, biological, geological, and hydrological data at an interaction zone between the Otter Tail River and adjacent surficial aquifer.

Stream-sediment nutrients site - Describe the roles of suspended sediment in transporting nutrients in streams. Map stream-channel geometry and collect sediment samples over spring runoff and rain-storm flows at selected sites in the Pembina River Basin.

DESCRIPTION OF MAP UNITS

Aquifers in the study unit.

Major surficial aquifer - Area of sand or sand and gravel deposits containing a saturated thickness sufficient to yield water to wells or springs. Mostly formed from glacial outwash, deltaic, or ice-contact deposits. May contain thin (less than 5 feet), discontinuous confining layers of silt and clay. Boundary dashed where approximated.

Major buried sand and gravel aquifer - Area of sand or gravel deposits buried within glacial till. Many of these aquifers are elongated glacial outwash or ice-contact deposits and contain discontinuous confining layers of silt and clay. Boundary dashed where approximated.

Major buried sand and gravel aquifer - Area of sand or gravel deposits buried within glacial till exhibiting a dissected areal distribution. Note that small, unconnected buried aquifers can exist anywhere within the glacial drift.

Beach-Ridge Deposit - Axis of major remnant shoreline deposits from various levels of glacial Lake Agassiz where sand and gravel in the vicinity of these ridges may be sufficiently saturated to yield water to wells or springs.

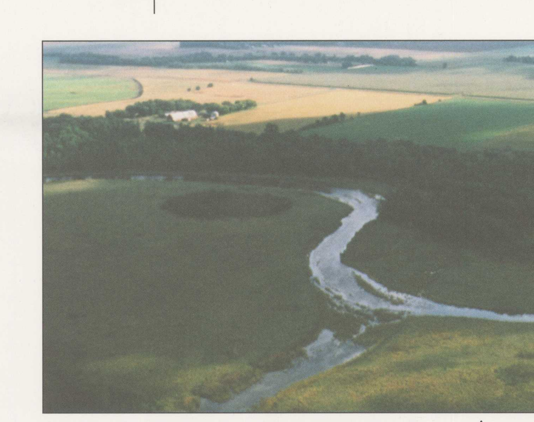
Potential area of saline ground water from sedimentary bedrock to overlying glacial sediments (subregion E).

Lower Cretaceous Rocks - Mostly sandstone with interbedded shale and siltstone with some lignite. Includes, from youngest to oldest units, Mowry Shale, Newcastle Sandstone, Skull Creek Shale, Fall River Sandstone, Fuson Formation, and Lakota Formation; last three units sometimes referred to as Inyan Kara Group and by water-well drillers as Dakota Sandstone.

Undifferentiated Jurassic Rocks - Interbedded varigated shale, anhydrite limestone, dolomite, and sandstone. Sometimes referred to as "red beds." May include some rocks of Triassic age.

Ordovician Rocks - Mostly limestone and dolomite with beds of shale and sandstone. Includes Red River and Winnipeg Formations (Winnipeg Group in North Dakota).

Boundary of study unit
Boundary of indicator basin
Boundary between primary subregions (physiographic areas) for sampling design.
Boundary between ecoregions where substantially different from physiographic areas.
Trace of section A-A'



Stream-aquifer interaction study site. (Looking northeast)

Figure 5. Sampling sites and generalized section in the Red River of the North Basin study unit.

Table 4. Coverage of sampling sites within the environmental framework and stratification, 1993-95.

Percent of study unit in this physiographic area-soil group framework. Numbers do not total 100 percent because open water was not included. — 3 (c) ECO-1 SW-5 SUS, LUS — Major land cover and land use: (a) cropland and pasture; (c) forest; (d) wetland. Sampling sites in stratum.

SW-ECO-n, n is the number of co-located indicator chemistry and ecological sites.
SW-n, n is the number of indicator chemistry sites.
ECO-n, n is the number of ecological sites.
LUS, the wells used for land-use study.
SUS, the wells used for study unit survey.

Physiographic area	Soil group 1	2	3	4	5	6
A	12 (a) SW-ECO[1]-3 ECO-3	12 (a) SW-ECO[1]-3	0	0	6 (a) SUS	0
B	26 (a)	0	0	17 (a) SW-ECO-1 LUS SUS	2 (a)	0
C	0	0	5 (d)	2 (c) SW-ECO-1 ECO-1	0	0
D	2 (a) SW[2]-.5	5 (a) ECO-1	0	1 (c) ECO[3]-1.5	3 (c) SW-ECO-1 SW[5]-1 ECO[7]-1.5	3 (c) ECO[4]-1 SW[6]-.5 SUS, LUS

[1] Two sites represent A1, 2 sites represent A2, and there are 2 sites that represent characteristics common to A1 and A2, averaging 3 sites to each stratum.
[2] This site represents D1 and D5.
[3] One site represents D4 exclusively and 1 site represents D4 and D5, averaging 1.5 ecological sites for this stratum.
[4] Two sites represent D5 and D6, averaging 1 ecological site for this stratum.
[5] Two sites represent this stratum, another one represents D1 and D5, and the other represents D5 and D6.
[6] This site represents D5 and D6, averaging .5 sites for this stratum.
[7] Three ecological sites represent this stratum, another one represents D4, and 2 represent D6, averaging 1.5 sites for this stratum.

Implications for Water-Quality Assessment

The large amount of water-quality and supporting data collected for the Red River Basin study unit will be analyzed within the context of the environmental framework described in this report. This analysis also will need to consider the hydrologic regime of the intensive sampling period relative to the average and range of hydrologic conditions known for the Red River Basin study unit. A suitable environmental framework with an associated sampling stratification could be valuable for future monitoring in the study unit, not only for identifying cause-and-effect relations, but to improve transferability of water-quality analysis to other parts of the basin not sampled during this study. The data will be analyzed to answer local and regional questions about water quality, and analyzed with data from other NAWQA study-units for national assessment.

A review of the 1993-95 data collection coverage shows that sampling stratification B1 (the Red River Valley Lake Plain and soil group 1) is under represented. This stratum constitutes a fairly large portion of the Red River Basin study unit and intensive cropland and pasture areas (fig. 5, table 4). There are few perennial streams that drain land strictly within this sampling stratum and there are no established gaging stations. Many of the integrator-type stream sites, however, include large areas of sampling stratum B1 (fig. 5, table 2). Soil group 3 in the Lake-Washed Till Plain (C3) and soil group 2 in the Moraine (D2) also were poorly represented during the 1993-95 cycle of sampling. These under sampled strata may be considered for future water-quality assessments.

Evaluation of water-quality results in terms of the environmental framework and sampling stratification is beyond the scope of this report. However, some recent investigators have noted some supporting evidence that the proposed environmental framework is technically valid. For example, Goldstein (1995), in a review of available biological data for the Red River Basin study unit, reported a relation between fish species richness and the number of ecoregions the river flowed through. Through cluster analysis of species within a fish community, he also identified groups of similar streams that closely approximated the stratification described in this report. Tornes and Brigham (1995) reported few detections and low concentrations and loads of pesticides in streams for the Red River Basin study unit from preliminary results from NAWQA sampling. They noted that although this is an intensive agricultural basin, factors such as flat land slope, organic-rich soils, and pesticide management could limit pesticide contamination. In a preliminary analysis of NAWQA land-use study data, Cowdery (1995) showed significant differences in shallow ground-water quality between the Sheyenne Delta and Otter Tail Outwash aquifers despite similarity in agricultural crops and irrigation. He suggested that differences in hydrology, soils, and associated agricultural practices caused the differences in measured water quality.

Summary

In 1991, a water-quality assessment began for the Red River of the North Basin study unit, which is one of 60 study units of the NAWQA Program. The program goals are to describe water-quality conditions for a large part of the Nation's freshwater streams and aquifers, describe how water quality is changing over time, and improve the understanding of the primary natural and human factors that affect water-quality conditions. The sampling design for the 1993-95 cycle of the Red River Basin study unit was developed to address large-scale questions, such as the presence, distribution, and loads of pesticides and nutrients associated with agricultural regions in the basin and across the Nation. Major local and regional concerns about water quality paralleled the national issues, but also included concerns about salinity effects from naturally occurring sources and sedimentation from erosion.

An environmental framework was used to design water-quality sampling for streams and aquifers of the Red River Basin study unit. The environmental framework for streams and surficial aquifers consists of land features, such as physiographic areas, soils grouped by drainage and texture characteristics, and land cover and land use. The dominant land use category is cropland and pasture and this category was subdivided further by primary crop patterns. A bedrock salinity component of the framework is used for buried aquifers in the glacial sediments which cover the study unit.

A hierarchy of the environmental-framework components was developed into the sampling-site stratification for the study unit. Glacial geology, climate, and hydrology of the study unit intrinsically relate to the framework components. Physiography is closely related to the surficial geology and hydrology. Soil associations groups are similar to each other within the four major physiographic areas. Land cover and land use are related to the soils and climate. All of these factors can affect the amount and concentration of chemicals and sediment in water.

Actual sampling design for streams, aquatic biology, and ground water were described within the proposed sampling-site stratification. Practical considerations of established sampling sites, background information from previous hydrologic investigations, and site suitability for sampling protocols also figured into final site selection. Not all of the sampling strata could be covered by the 1993-95 sampling. Preliminary results from NAWQA data analysis support the proposed sampling design.

The design includes measures for chemistry in streams and shallow aquifers; suspended sediment and bottom sediments in streams; the variety and number of fish, macroinvertebrates (bugs), and algae in streams; and contaminants in fish tissues. Stream sites, biological species, and shallow aquifers were sampled to represent the primary water resources in the basin. Wherever feasible, sampling sites for streams and aquatic biology were co-located in order to assess water-quality conditions using a variety of indicators.

Hydrologic characteristics were compiled to (1) indicate volume and energy of water generally available to transport chemicals and sediment from the land to streams, (2) describe conditions that can affect the distribution and presence of organisms in streams, and (3) estimate leaching of surface chemicals to shallow ground water. Selected statistics for the period 1947-94 show that streamflow, runoff, coefficient of variation, and 90-percent exceedence flow relate to the physiographic areas. Streams draining the Moraine area had the largest baseflows, the largest mean-annual runoffs (2.83 to 3.41 inches), and the smallest year-to-year variation in streamflows. Streams draining the Drift Prairie area had the smallest baseflows and mean-annual runoffs (0.40 to 1.03 inches) and the largest year-to-year variability in streamflows.

The large amount of water-quality and supporting data collected for this study will be analyzed within the context of the environmental framework described in this report. This analysis also will need to consider the hydrologic regime of the intensive sampling period relative to the average and range of hydrologic conditions known for the Red River Basin study unit. The mean annual runoff for 1993-94 was 0.13 to 3.10 inches greater than the mean annual runoff for 1947-94. Ground-water levels indicated that summer recharge to the Sheyenne Delta aquifer was above normal when wells were sampled in 1993. The environmental framework and associated sampling stratification could be valuable for future monitoring in the study unit not only for identifying cause-and-effect relations, but to improve transferability of water-quality analysis to other parts of the study unit that were not sampled.

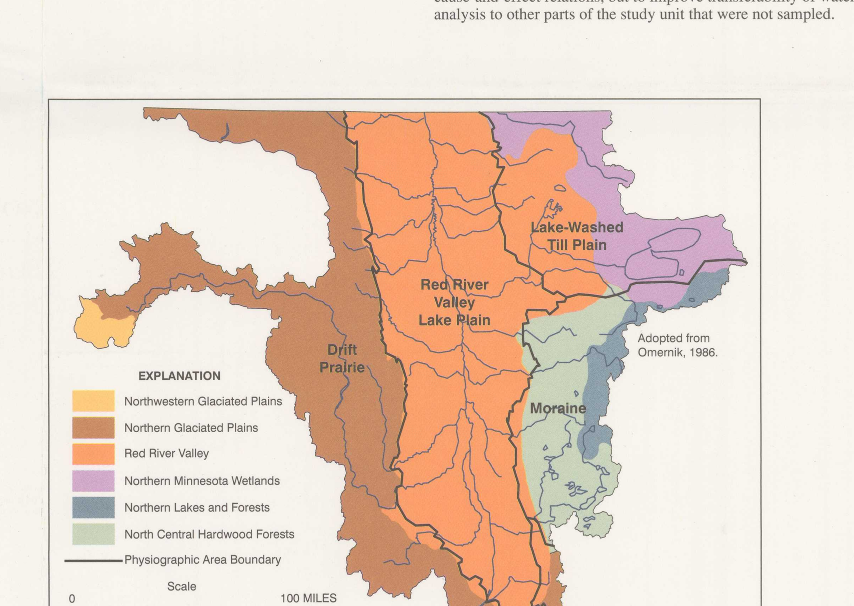


Figure 6. Ecoregions [modified from Omernik, 1986] and physiographic areas of the Red River of the North Basin Study Unit

Table 2.—Basin characteristics and stratification of stream-sampling sites.

[Site type: (i, indicator), basin drains relatively homogeneous land characteristics; (I, integrator), basin drains mixture of land characteristics; water-quality indicators: chem, water-column chemistry and suspended sediment; eco, aquatic biota; p, water column sampled at least monthly for large suite of pesticides; drainage area, based on analysis from this study; mi^2, square miles; ft^3/s, cubic feet per second; mi/mi^2, miles per square mile; percent area, category area divided by basin area times 100 (note: water area not included for soils categories); sampling-site stratification: physiography (A-D), soil groups (1-6), and land cover or land use (a-f) from table 1; stratification class based on percent area more than 50 percent or two categories in a group more than 66 percent.]

Map number (fig. 5)	Station number	Site name	Latitude, longitude (degrees minutes seconds)	Site type (i=indicator, I=integrator) and water-quality indicators (chem, chemistry; eco, ecology; p, pesticides)	Drainage area (mi^2)	Years of no record during 1947 through 1994	Mean annual discharge [1947-1994] (ft^3/s)	Mean annual runoff [1947-1994] (inches)	Mean annual discharge [1993-1994] (ft^3/s)	Mean annual runoff [1993-1994] (inches)	90th percent exceedence discharge [1947-1994] (ft^3/s)	Coefficient of variation of mean annual streamflow [1947-1994] (percent)	Drainage density (mi/mi^2)	(A) Drift Prairie (percent area)	(B) Red River Valley Lake Plain, including beaches (percent area)	(C) Lake-Washed Till Plain (percent area)	(D) Moraine (percent area)	Soil group 1, poorly drained, fine texture (percent area)	Soil group 2, moderately-well drained, fine texture (percent area)	Soil group 3, poorly drained, organic material (percent area)	Soil group 4, poorly drained, coarse texture (percent area)	Soil group 5, moderately-well drained, coarse texture (percent area)	Soil group 6, excessively-well drained, coarse texture (percent area)	(a) Cropland and pasture (percent area)	(b) Grassland (percent area)	(c) Forest (percent area)	(d) Wetland (percent area)	(e) Water, or other (percent area)	(f) Urban (percent area)	Major crops [2](1991)	Sampling-site stratification: A-D, physiography; 1-6, Soils group; a-f, land use
1	05030140	Otter Tail River NW of Luce, Minn.	464020, 0953956	i, eco	325	new	--	--	--	--	--	--	0.20	0	0	0	100	0	0	0	0	61	35	25	0	53	9	13	<1	Cw	D5c
2	05030150	Otter Tail River near Perham, Minn.	463834, 0953615	i, chem	336	new	--	--	--	--	--	--	.20	0	0	0	100	0	0	0	0	61	35	25	0	53	9	13	<1	Cw	D5c
3	05046000	Otter Tail River below Orwell Dam near Fergus Falls, Minn.	461235, 0961105	i, chem	1740	0	385	3.00	622	4.85	97.6	41	.13	2	0	0	98	0	12	0	0	43	40	56	0	23	5	15	<1	Cw	D5,6a
4	05051300	Bois de Sioux River near Doran, Minn.[3]	460908, 0963444	i, chem, eco	1550	0	87.8	1.03	353	4.13	0	117	.12	52	47	0	1	61	32	0	3	2	1	94	0	0	3	2	<1	Cs	A1a
5	05053800	Red River of the North above Fargo, N. Dak.[4]	464814, 0964747	I, chem, p	6610	0	734	1.49	1,630	3.30	93.2	64	.14	36	37	0	27	44	19	0	10	14	11	84	1	7	2	5	<1	Cs	mix
6	05054020	Red River of the North below Fargo, N. Dak.[4]	465550, 0964705	I, eco	6710	0	734	1.49	1,630	3.30	93.2	64	.14	35	38	0	27	45	18	0	10	14	11	84	1	7	2	5	1	Cs	mix
7	05056000	Sheyenne River near Warwick, N. Dak.	474820, 0984257	i, chem, eco	1880	3	54.9	.40	85.2	.61	1.1	73	.10	100	0	0	0	6	55	0	5	33	1	79	16	0	2	2	<1	Wf	A2a
8	05058700	Sheyenne River at Lisbon, N. Dak.	462649, 0974044	i, chem, eco	4490	10	163	.49	405	1.22	14.7	72	.11	100	0	0	0	27	44	0	4	25	1	86	10	1	2	1	<1	Wf	A2,1a
9	05059000	Sheyenne River near Kindred, N. Dak.	463735, 0970005	I, chem	5000	3	203	.55	457	1.24	33.5	67	.12	94	6	0	0	27	42	0	6	24	1	84	11	1	2	1	<1	Wf	mix
10	05059700	Maple River near Enderlin, N. Dak.	463735, 0973425	i, eco	828	10	43.1	.71	128	2.10	1.4	94	.04	100	0	0	0	63	36	0	0	1	0	97	1	0	1	1	<1	Wf	A1a
11	465149096280401	Buffalo River at Buffalo R. State Park near Glyndon, Minn.[5]	465149, 0962804	i, eco	380	1.9	72.7	3.06	105	4.43	13.5	47	.25	0	2	0	98	8	74	0	0	14	4	74	0	15	4	7	<1	W	D2a
12	471931095564601	Wild Rice River near Mahnomen, Minn.	471931, 0955646	i, eco	386	new	--	--	--	--	--	--	.27	0	0	0	100	9	5	5	6	46	27	26	0	57	11	5	<1	W	D5,6c
13	05062500	Wild Rice River at Twin Valley, Minn.	471600, 0961440	i, chem, eco, p	929	6	194	2.83	317	4.63	21.3	52	.22	0	2	0	98	30	18	2	8	28	12	50	0	37	8	5	<1	Wf	D1,5a
14	05064500	Red River of the North at Halstad, Minn.	472110, 0965050	I, chem	17,300	14	1,800	1.41	3,330	2.61	206	57	.16	48	31	0	21	41	27	0	10	16	5	85	4	5	2	3	<1	W	mix
15	05066500	Goose River near Hillsboro, N. Dak.	472434, 0970339	i, eco	1,240	0	86.2	.94	177	1.94	.3	95	.21	58	42	0	0	62	22	0	11	5	0	96	1	1	1	0	<1	W	A1a
16	473130096155001	Sandhill River at Fertile, Minn.[6]	473130, 0961550	i, eco	216	.7	71.2	2.25	104	3.28	8.48	60	.23	0	1	0	99	11	2	0	67	20	0	87	0	7	4	2	<1	W	D4a
17	475331096144601	Red Lake River at Red Lake Falls, Minn.	475331, 0961446	I, eco	3,580	new	--	--	--	--	--	--	.18	0	1	83	17	5	0	30	44	5	3	29	0	26	31	14	<1	W	mix
18	475000095254501	Clearwater River at Berner, Minn.	475000, 0952545	i, eco	359	new	--	--	--	--	--	--	.24	0	0	22	78	11	0	12	16	36	26	35	0	41	21	2	<1	W	D5,6c,a
19	05078500	Clearwater River at Red Lake Falls, Minn.	475315, 0961625	i, eco	1,360	.4	342	3.41	378	3.77	43.5	53	.30	0	14	34	51	9	0	11	44	29	7	67	0	19	11	2	<1	W	D4,5a
20	05079000	Red Lake River at Crookston, Minn.	474632, 0963633	I, chem, eco	5,270	0	1,310	3.37	1,360	3.50	163	55	.21	0	10	66	25	9	0	23	43	12	4	43	0	23	24	10	<1	W	mix
21	05082500	Red River of the North at Grand Forks, N. Dak.	475538, 0970134	I, chem	25,700	0	3,230	1.71	5,280	2.79	434	55	.17	36	30	14	20	36	20	5	18	14	4	78	3	9	6	4	<1	W	mix
22	05082625	Turtle River at Turtle R. State Park near Arvilla, N. Dak.	475618, 0973000	i, chem, eco, p	254	new	--	--	38.4	2.05	--	--	.14	72	28	0	0	30	46	0	19	5	0	96	1	1	1	0	<1	We	A2,1a
23	05084000	Forest River near Fordville, N. Dak.[7]	481150, 0974349	i, eco	405	0	43.3	.79	55	1.01	.29	95	.10	99	1	0	0	73	18	0	0	9	0	95	1	1	2	0	<1	W	A1a
24	05085900	Snake River above Alvarado, Minn.	481027, 0965950	i, chem, eco, p	218	new	--	--	44.5	2.77	--	--	.26	0	58	42	0	32	0	2	51	15	0	91	1	4	3	0	<1	Wf	B4a
25	484851097104301	Red River of the North at Joliette, N. Dak.	484851, 0971043	I, eco	30,700	new	--	--	--	--	--	--	.18	31	38	14	16	40	17	5	21	12	3	82	2	8	6	3	<1	W	mix
26	05094000	Two Rivers at Lake Bronson, Minn.	484447, 0964320	i, eco	446	new	--	--	--	--	--	--	.12	0	12	88	0	0	0	10	78	13	0	71	0	8	21	0	<1	W	C4a
27	05099600	Pembina River at Walhalla, N. Dak.	485452, 0975457	i, chem, eco	3,200	3	225	.95	272	1.15	1.7	91	.05	99	1	0	0	67	24	0	0	9	0	89	2	6	2	1	<1	W	A1a
28	05102500	Red River at Emerson, Manitoba	490030, 0971240	I, chem, p	35,600	0	4,210	1.60	6,220	2.37	460	58	.17	37	36	13	14	43	18	4	19	12	3	81	2	8	6	3	<1	W	mix
29	05112000	Roseau River at Caribou, Minn.	485854, 0962746	i, chem, eco	1,560	10.4	277	2.41	385	3.35	3.91	68	.22	0	0	100	0	15	0	28	54	4	0	54	0	15	30	0	<1	W	C4a

Table 2 footnotes:

[1] Percent areas for this component may not total 100 percent for basins containing large areas of open water.
[2] Data source: Minnesota Agricultural Statistics Service (1993) and North Dakota Agricultural Statistics Service (1992); national crop categories from R.J. Gilliom and G.P. Thelin (written commun., 1996); major crops: Cw, corn more than 20 percent and wheat and other small grains more than 20 percent; Cs, corn more than 20 percent and soybeans more than 20 percent; W, wheat and other small grains more than 50 percent; Wf, wheat and other small grains more than 50 percent and sunflowers more than 10 percent; We, wheat and other small grains more than 50 percent and edible beans more than 10 percent (dried beans and peas more than 10 percent for national category).
[3] Hydrologic data for 1947-94 period were estimated from nearby stream-gaging station Bois de Sioux River near White Rock, S. Dak., drainage area 1,160 mi^2.
[4] Hydrologic data for 1947-94 period were estimated from nearby stream-gaging station Red River at Fargo, N. Dak., drainage area 6,700 mi^2.
[5] Hydrologic data for 1947-94 period were estimated from nearby stream-gaging station Buffalo River near Hawley, Minn., drainage area 322 mi^2.
[6] Hydrologic data for 1947-94 period were estimated from nearby stream-gaging station Sandhill River at Climax, Minn., drainage area 428 mi^2.
[7] Hydrologic data for 1947-94 period were estimated from nearby stream-gaging station Forest River at Minto, N. Dak., drainage area 740 mi^2.

Table 3.—Summary characteristics and stratification for ground-water sampling sites.

[Values for saturated thickness, potential well yield, and transmissivity compiled from U.S. Geological Survey Hydrologic Atlases and water-resources studies in Minnesota and South Dakota, and North Dakota State Water Commission ground-water studies of North Dakota counties; aquifer area used in random stratified well selection for sampling (Scott, 1990); gal/min, gallons per minute; ft/day, feet per day; $ft^3/ft/day$, cubic feet per foot per day; mi^2, square miles; --, data not available or not applicable]

Map identification (fig. 5)	Well group by study component	General description of aquifers	Range in saturated thickness (feet)	Range in potential well yield (gal/min)	Range in hydraulic conductivity (ft/day)	Range in transmissivity ($ft^3/ft/day$)	Aquifer area used in well search (mi^2)	Number of wells in group[2]	Well use	Median and {range} in well diameter (inches)	Median and {range} in well depth (feet)	Median and {range} in screened interval length (feet)	Median and {range} in depth to water (feet)	Primary soils group (from table 1)	Primary land cover and land use within 1/2-mile radius of well	Sampling-site stratification: A-F, physiography and bedrock salinity; 1-6, soils group; a-f, land use (from table 1)
	Study-unit surveys															
DP01-DP15	Drift prairie surficial aquifers	Sand and gravel deposited mostly in glacial-outwash plains and proglacial channels; predominantly well-sorted very fine grained sand to medium gravel, calcareous source rock.	10-130	10-1,500	--	200-32,000	1,090	15	Mostly domestic, some observation	2 {2-36}	38 {8-64}	5 {2.3-6}	13 {2-34}	4	Cropland and pasture and grassland	A4a
AB01-AB29	Red River Valley Lake Plain surficial aquifers	Sand and silt deposited in deltas or beach ridges associated primarily with glacial Lake Agassiz basin; predominantly well-sorted fine- to coarse-grained sand, occasionally interfingered with silt and clay; beach deposits have lenses of gravel.	10-87	10-1,000	--	130-8,600	1,770	[3]29	Mostly observation, some domestic	2 {2-6}	39 {10-92}	5 {4-26}	9 {2-27}	4,5	Cropland and pasture	B4,5a
MM01-MM25	Moraine surficial aquifers	Sand and gravel deposited mostly in glacial-outwash plains, proglacial channels or ice-contact features; predominantly well-sorted medium-grained sand to medium gravel; crystalline (siliceous) source rock.	10-130	10-1,500	--	200-32,000	1,080	25	Mostly domestic, some observation	4 {2-5}	55 {15-110}	4 {2-15}	20 {2-55}	6	Cropland and pasture and forest	D6a,f
RT01-RT42	Regional transect of buried aquifers	Sand and gravel deposits of glacial outwash and channels buried within glacial till; sandstone or limestone confined between shale or other low-permeable rock.	10-550	10-1,500	--	110-56,000	15,000	[3]42	Mostly domestic, some observation	4 {2-12}	121 {34-733}	6 {4-82}	19 {-2-87}	--	--	E,F
RS16, RS17, RS24, RS25	Regional transect of surficial aquifers	Surficial sand and gravel of glacial deposits from all physiographic areas.	10-130	10-1,500	--	--	--	[3]24	Mostly domestic, some observation	2 {2-36}	39 {8-92}	5 {2-9}	12 {2-27}	--	--	E,F
	Land-use studies															
SD	Sheyenne Delta aquifer beneath irrigated cropland	Sand and silt deposited in large glacial delta; predominantly well-sorted fine- to coarse-grained sand, occasionally interfingered with silt and clay; part of the area reworked by wind forming sand dunes.	10-120	3-1,000	[4].001-35	140-5,200	154	29	Mostly observation, some domestic	2 {2-4}	15 {10-67}	4 {5-10}	5 {1-24}	4	Cropland and pasture	B4a
OT	Otter Tail Outwash aquifer beneath irrigated cropland	Sand and gravel deposited in glacial-outwash plain; well-sorted medium-grained sand to medium gravel; crystalline source rock.	10-80	10-12,000	[5]90-600	800-27,000	82	29	Mostly observation, some domestic	2 {2-4}	26 {9-75}	4 {3-10}	15 {2-33}	6	Cropland and pasture	D6a
	Ground-water flowpath studies															
SF	Sheyenne Delta aquifer and Sheyenne River	Sand and silt deposited in large glacial delta; predominantly well-sorted fine- to coarse-grained sand, occasionally interfingered with silt and clay; part of the area reworked by wind forming sand dunes.	40-80	10-500	[4]10-35	800-2,000	--	9	Observation only	2 {2}	19 {12-53}	9 {4-10}	6 {2-15}	4	Cropland and pasture	B4a
OF	Otter Tail Outwash aquifer and Otter Tail River	Sand and gravel deposited in glacial-outwash plain; well-sorted medium-grained sand to medium gravel; crystalline source rock.	10-80	10-12,000	[5]90-370	1,600-14,000	--	13	Observation only	2 {2}	27 {11-75}	4 {2-9}	6 {-2-30}	6	Cropland and pasture	D6a

Table 3 footnotes:

[1] Data missing on less than 25 percent of the wells used in the study-unit surveys for statistics on well diameter, screened interval, and depth to water.
[2] Some wells included in the land-use and flowpath studies also were used in the study-unit survey (fig. 5).
[3] Includes a few wells from a ground-water study in northwestern Minnesota (Lindgren, 1996); twenty of these ewlls were used in other groups of the study-unit surveys and are identified as DP, AB, or MM on figure 5.
[4] Data from Downey and Paulson (1974).
[5] Data from Reeder (1972) and numerical modeling of ground-water flow for this study.

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1997

Sampling Design for Assessing Water Quality of the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993-1995

By D.L. Lorenz and J.D. Stoner, 1996