Hydrology and Relation of Selected Water-Quality Constituents to Selected Physical Factors in Dakota County, Minnesota, 1990-91

By James E. Almendinger and Gregory B. Mitton

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Conversion Factors, Vertical Datum, and Abbreviations

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter
foot (ft)	.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	.02832	cubic meter per second

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentrations: Chemical concentrations of substances in water are given in metric units of milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical values are the same as for concentrations expressed in parts per million.

Water year: A water year is from October 1 of the previous year through September 30 of the stated year. For example, the 1990 water year is from October 1, 1989 through September 30, 1990.

HYDROLOGY AND RELATION OF SELECTED WATER-QUALITY CONSTITUENTS TO SELECTED PHYSICAL FACTORS IN DAKOTA COUNTY, MINNESOTA, 1990-91

By James E. Almendinger and Gregory B. Mitton

Abstract

Selected water-quality constituents were determined in water from 5 surface-water sites and 29 wells in Dakota County, Minnesota, to search for possible relations to selected physical factors, including waste-water discharge, agricultural land, Quaternary deposits, bedrock, soil-leaching potential, and water-table depth. All surface-water samples were from the Vermillion River Basin, whose hydrologic setting was studied to determine its relation to the ground-water flow in the surrounding surficial sand aquifer. Each site was sampled from 1 to 12 times during 1990-91. A total of 198 samples were collected; selected samples were analyzed for major inorganic ions, nutrients, and triazine content. Physical factors within the area of land assumed to be contributing water to each sampling site were determined from existing mapped or digitized sources. Nitrate concentrations in ground water were related to agricultural land and soil-leaching potential. Nitrate concentrations were large (median 13.2 milligrams per liter as nitrogen) where the percentage of agricultural land in the contributing area was large (equal to or greater than 75 percent) and where the soils had a large soil-leaching potential. Nitrate concentrations were small (median 3.2 milligrams per liter as nitrogen) where the soils had a small soil-leaching potential, despite a large percentage of agricultural land. The statistical relation was not particularly strong, however: the null hypothesis that sites with different soil-leaching potentials had the same nitrate concentrations in ground water was rejected by the Kruskal-Wallis test at only the probability $P = 0.15$ level. Water-table depth was not an important factor in the relation between nitrate concentrations in ground water and agricultural land. Discharge from a waste-water treatment plant provided most of the downstream loading of nitrate into the Vermillion River mainstem. Triazines were found in small concentrations (less than 2 micrograms per liter) in the Vermillion River and its tributaries. No relation was apparent between selected water-quality constituents and either Quaternary deposits or bedrock.

Introduction

State and local officials in Minnesota are concerned about the potential effects of agricultural chemicals such as fertilizers and pesticides on water quality in Dakota County (fig. 1). The central part of the county is covered by a surficial sand aquifer. This area is farmed extensively and the aquifer is susceptible to contamination by nutrients and pesticides applied to the fields. These chemicals could contaminate the water in the surficial sand aquifer and eventually migrate into the underlying bedrock Prairie du Chien-Jordan aquifer, which is widely used for domestic drinking-water supplies (Balaban and Hobbs, 1990). These contaminants could also move to the Vermillion River in central Dakota County and consequently affect surface-water quality there.

Effective water-quality management requires knowledge of the local hydrology and of the physical factors that affect water quality. The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources, the Legislative Commission on Minnesota Resources, and the Dakota County Soil and Water Conservation District, initiated a study in 1989 to investigate the hydrology of the Vermillion River Basin and to relate selected water-quality constituents to selected physical factors in Dakota County.

Physical factors that can affect water quality are categorized in this report as source factors and transport factors (fig. 2). Source factors include both natural and human-caused potential sources of chemical constituents in water. Some source factors, such as a waste-water discharge, are present at known locations and are called point sources. Other source factors are

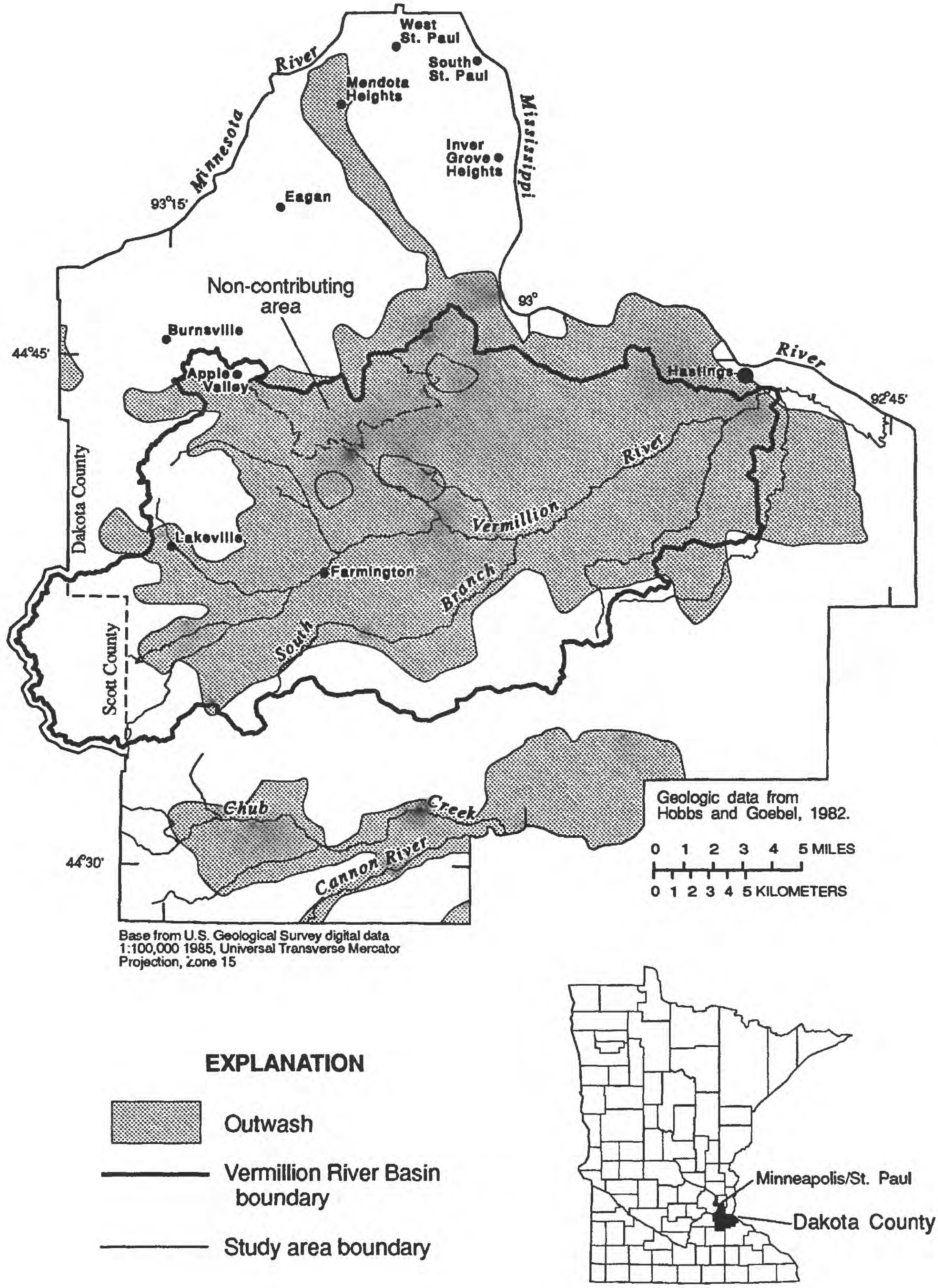


Figure 1.--Vermillion River Basin, outwash deposits, and major municipalities, Dakota County, Minnesota.

present over larger land surface areas or underground volumes and are called spatially distributed sources. Agricultural land, Quaternary deposits, and bedrock are examples of spatially distributed sources. Transport factors affect the flow path or travel time of water as it flows from a given source to the water sampling location. Soil-leaching potential and water-table depth are examples of transport factors. Other transport factors not examined in this report include hydraulic conductivity and hydraulic gradient.

Purpose and Scope

The purpose of this report is to investigate the hydrology of the Vermillion River Basin and to relate selected water-quality constituents to selected physical factors in Dakota County, both within and beyond the Vermillion River Basin. The study area includes Dakota County plus the part of the Vermillion River Basin that extends into Scott County to the west. Physical factors examined were waste-water discharge, agricultural land, Quaternary deposits, bedrock, soil-leaching potential, and water-table depth. The scope is limited to data from five surface-water sampling sites and 29 wells, and to information from the literature and other public sources. A total of 49 samples of surface water and 149 samples of ground water were collected from spring 1990 to summer 1991. Selected water samples were analyzed for major inorganic ions, nutrients, and triazine herbicides.

Geology of Study Area

The surficial geologic deposits (drift) of Dakota County are dominated by unconsolidated glacial deposits, although bedrock outcrops are common in the southern part of the county (Hobbs and Goebel, 1982; Balaban and Hobbs, 1990). The glacial history of Dakota County is complex because mineralogically distinct deposits originated from different ice lobes. The southeastern part of the county has exposures of non-calcareous early or pre-Wisconsin drift. In later Wisconsin time (about 20,000 years ago), ice from the Superior lobe advanced from the northeast and deposited non-calcareous drift as end moraine in the northern and northwestern parts of the county and as outwash in the central part. Finally, calcareous drift was deposited by the Des Moines lobe, which advanced from the northwest about 18,000 to 14,000 years ago. This lobe lapped onto the existing moraine along the northwestern boundary of the county and continued south to form a low moraine along the western boundary of the county. An eastward-trending corridor of outwash was deposited at that time along the present course of the Vermillion River (Wright, 1972).

Small areas of Cambrian sandstone and dolostone subcrop in buried bedrock valleys in northern and eastern Dakota County. These valleys were channels of the Mississippi River during previous interglacial periods and are mostly filled with drift (Wright, 1972). The Prairie du Chien Group dolostone of Ordovician age is the most extensive bedrock subcrop unit in Dakota County (Balaban and Hobbs, 1990). The Prairie du Chien Group and the underlying Jordan Sandstone of Cambrian age function as a single aquifer over much of their extent (Adolphson and others, 1981). Overlying the Prairie du Chien Group is the St. Peter Sandstone, a poorly cemented sandstone of Ordovician age that forms the second-most extensive bedrock subcrop unit in Dakota County. Small areas of younger Ordovician carbonate and shale bedrock units overly the St. Peter Sandstone, especially in the northern part of the county (Balaban and Hobbs, 1990).

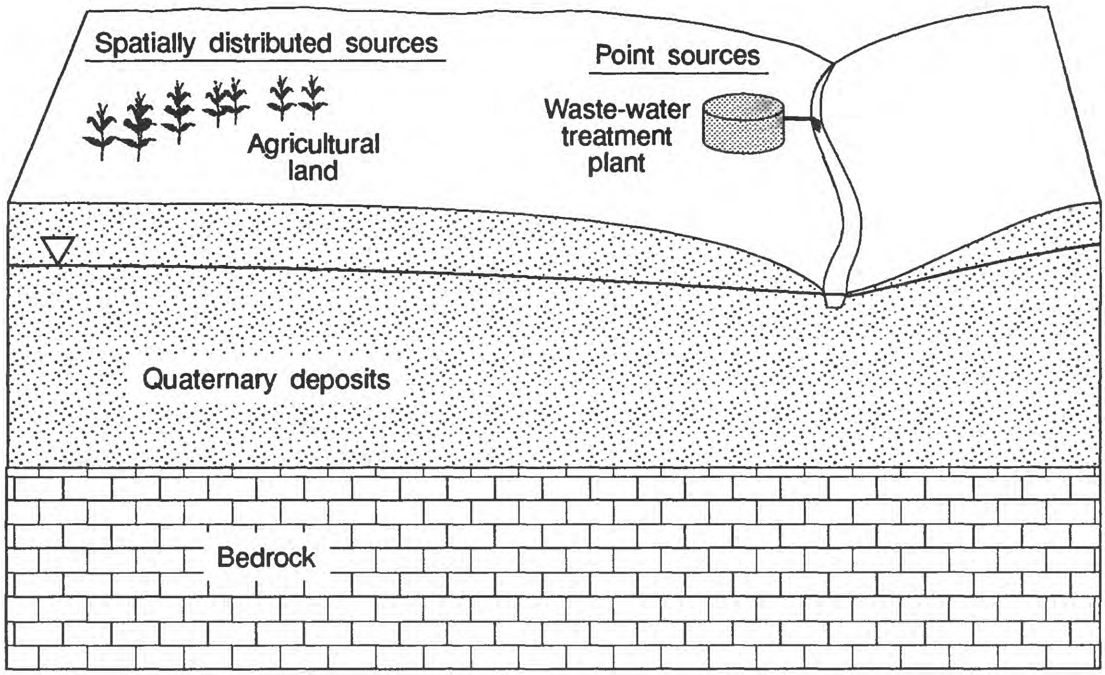
Previous Investigations

The general hydrology of the Minneapolis-St. Paul area is discussed by Norvitch and others (1973). They evaluated the water-resource availability for the area and calculated overall water budgets for various regions in their study area, which included the northern and central parts of Dakota County.

The U.S. Geological Survey conducted a sampling program from 1972 to 1978 to assess lake-water quality in relation to urbanization in northern Dakota County (Have, 1980; Ayers and others, 1980; Payne, 1980; Have and others, 1981). The reports concluded that urbanization generally increases nutrient loadings to lakes, notably phosphorus loading. Several of the reports tested regression models that could be used to predict phosphorus loadings. The reports also documented that urban runoff increased chloride concentrations and specific conductances of lake water. Tornes (1989) did follow-up sampling during 1982-83 and showed that chloride and specific conductance had increased in a number of lakes since the earlier sampling.

Ayers and others (1985) investigated runoff from small watersheds in the Minneapolis-St. Paul area to characterize loads from spatially distributed sources and to investigate transport mechanisms of various dissolved constituents. The authors concluded that amount of streamflow determined loadings of most constituents, in spite of negative correlations between

A. Selected source factors



B. Selected transport factors and water-flow paths

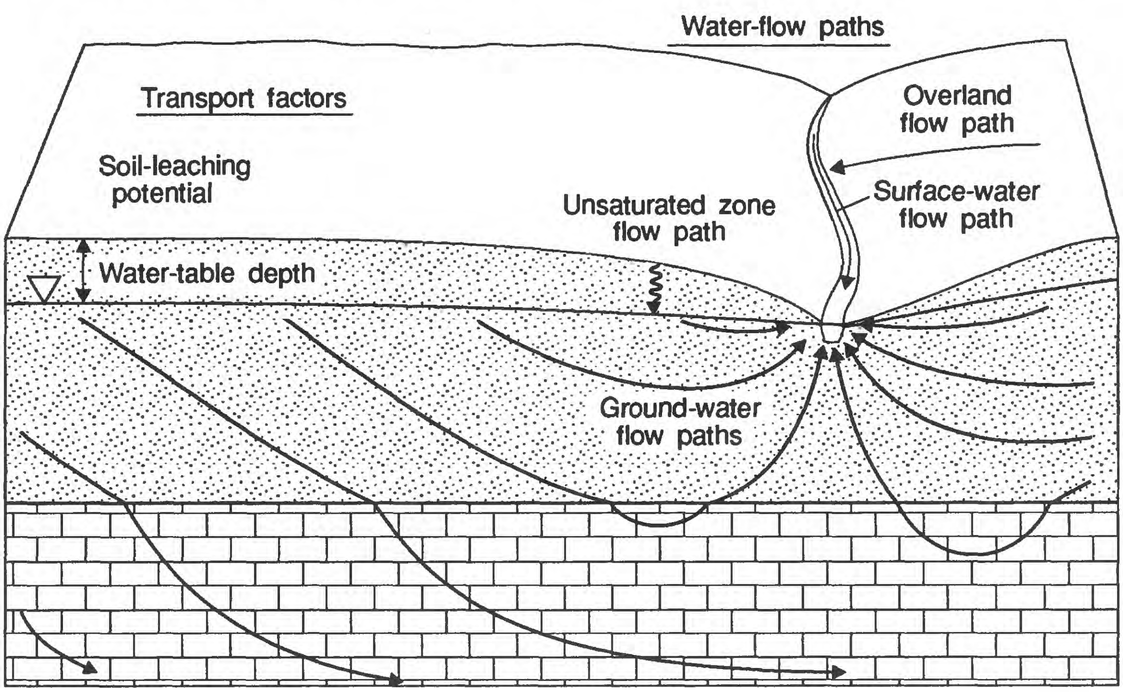


Figure 2.--Selected physical factors and water-flow paths that can affect water quality: A. Selected source factors, B. Selected transport factors and water-flow paths.

concentration and streamflow for many constituents. One of the watersheds studied was the South Branch Vermillion River, which is included in the present study area. Ayers and others (1985) found this watershed to be different from many of the others, possibly because of the large amount of irrigation in the basin and the large baseflow component of streamflow. Anderson and others (1987) studied rainfall-runoff relations for the Vermillion River and determined that 73 percent of the basin had a small runoff potential.

Ground water in drift and bedrock aquifers in Dakota County tends to be of the calcium-magnesium-bicarbonate type (Winter, 1974; Ruhl and others, 1983; Ruhl and Wolf, 1983; and Ruhl, 1987). Reeder and Norvitch (1974) examined a contaminated ground-water plume in a heavily industrialized area in northeastern Dakota County. They found elevated concentrations of many chemical constituents, including phenols, and smaller pH values in the contaminated plume. None of the wells in the present study are located in the contaminated area delineated by Reeder and Norvitch (1974).

The present study produced two earlier reports. Lorenz and Trotta (1991) examined computer methods of mapping water-table depth in Dakota County. Almendinger (1991) described the relation of nitrate concentrations in ground water to agricultural land and soil-leaching potential in Dakota County.

Methods of Investigation

This section describes the methods used to investigate the hydrology, water quality, contributing areas, and physical factors in the study area.

Hydrology

Five sampling sites were established in the Vermillion River Basin at two locations along the main stem (sites 2 and 5, fig. 3) and near the mouths of three tributaries (sites 1, 3, and 4, fig. 3). These sites will be referred to as the five Vermillion River sites in this report. A water-table well is a well with a screen intersected by the water table. A water-table well was installed in the drift within about 50 feet of the river at each of the five Vermillion River sites. In this report, the term "deeper well" refers to a well located within 10 horizontal feet of a water-table well and constructed with a 3-foot screen placed about 10 to 30 feet below the water table. A deeper well was installed in the drift at each of sites 1-4. Water levels in the river, water-table well, and deeper well were compared to estimate whether ground water was moving toward or away from the river at each site.

Streamflow was measured at each of the five Vermillion River sites from 9 to 12 times during 1990-91. At other times during the 1990 water year (October 1, 1989 through September 30, 1990) streamflow was estimated with stage-streamflow relations for sites with stage recorders. Site 2 was instrumented with a continuous stage recorder that was operated year-round; sites 3 and 5 were instrumented with continuous stage recorders for the ice-free periods of 1990-91. Subbasins above the five sampling sites were delineated on 1:24,000-scale topographic maps and digitized to obtain areas by using geographic information system software.

Water quality

Selected samples were analyzed for major inorganic ions, nutrients, and triazine content. In this report, water quality refers primarily to four selected water-quality constituents: specific conductance, calcium, nitrate, and triazines. Specific conductance was chosen because it is an overall measure of the ionic content of the water. Calcium was chosen because it can originate from dissolution of minerals in the Quaternary deposits and bedrock. Nitrate and triazines were chosen because they commonly originate from agricultural land. Other water-quality constituents sometimes showed patterns similar to these four in their variability with time and relation to selected physical factors.

In this report, sampling "site" refers to a small area (radius about 50 feet or less) where water samples are collected, sampling "point" refers to a location within a sampling site where a certain sample type was collected, and sample "type" refers to the kind of water sample collected within a site (table 1). The 25 sampling sites include the five Vermillion River sites plus 20 domestic wells. The three sampling points within the Vermillion River sampling sites included the river or tributary stream, a water-table well, and a deeper well (except at site 5). Each domestic well sampling site had only one sampling point, namely the well itself. The four sample types included surface water collected from the river or tributary stream, shallow ground water collected from the water-table wells, deeper ground water collected from the deeper wells, and domestic well water collected from the domestic wells.

Samples for water-quality analyses were collected 10 to 12 times during 1990-91 at the five Vermillion River sites (fig. 3). Depth-integrated surface-water samples

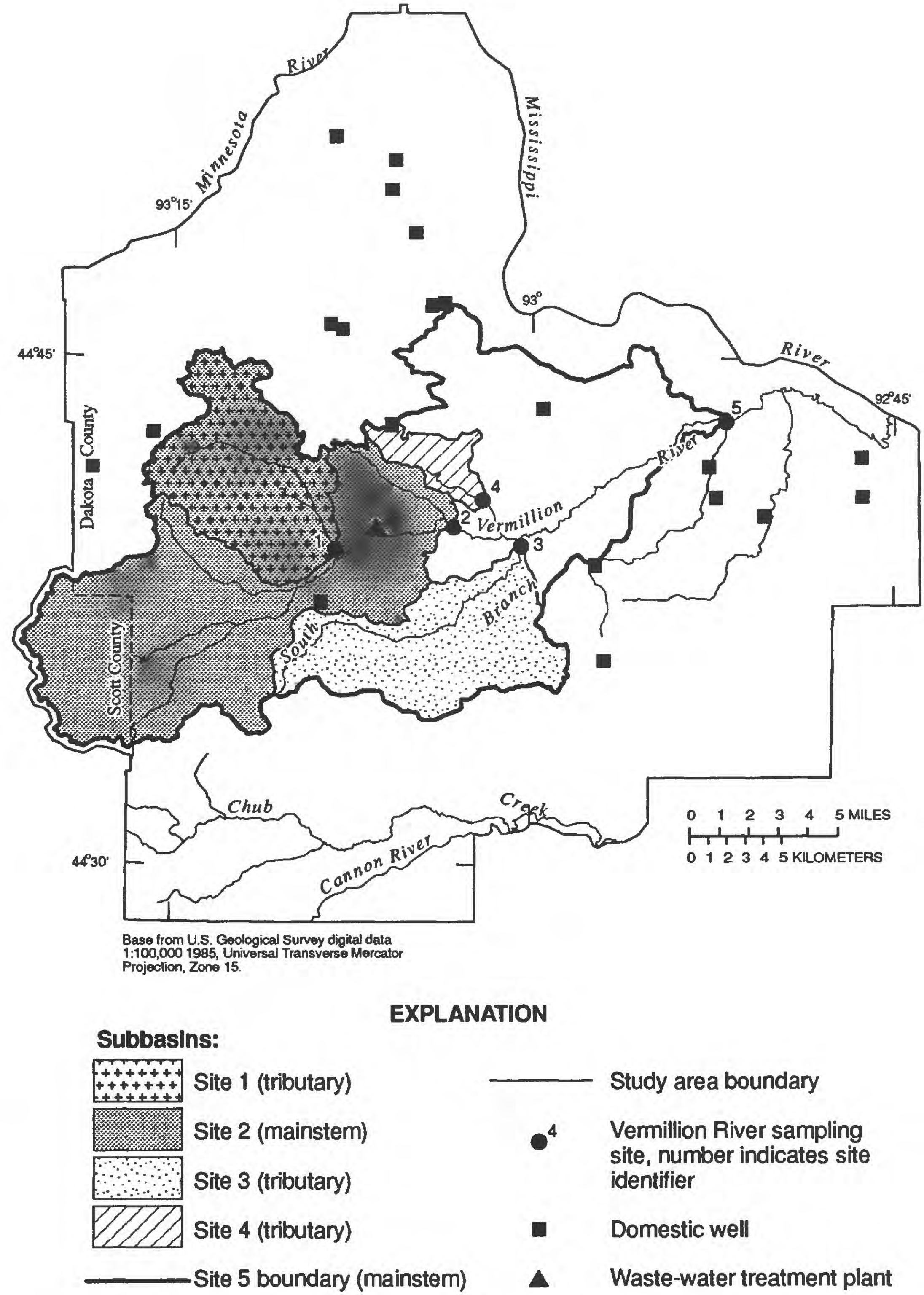


Figure 3.--Locations of five Vermillion River sampling sites, five subbasins of the Vermillion River, 20 domestic wells, and a waste-water treatment plant in Dakota County, Minnesota.

Table 1.--Description of sampling sites, sampling points, and sample types of water samples collected in Dakota County, Minnesota

	Sampling site	Sampling point	Sample type
	Vermillion River 1	Vermillion River 1	Surface water
		Water-table well 1	Shallow ground water
		Deeper well 1	Deeper ground water
	Vermillion River 2	Vermillion River 2	Surface water
		Water-table well 2	Shallow ground water
		Deeper well 2	Deeper ground water
	Vermillion River 3	Vermillion River 3	Surface water
		Water-table well 3	Shallow ground water
		Deeper well 3	Deeper ground water
	Vermillion River 4	Vermillion River 4	Surface water
		Water-table well 4	Shallow ground water
		Deeper well 4	Deeper ground water
	Vermillion River 5	Vermillion River 5	Surface water
		Water-table well 5	Shallow ground water
	20 domestic wells	20 domestic wells	Ground water
Total	25 sampling sites	34 sampling points (5 surface-water sampling points, and 29 ground-water sampling points)	

(49) were collected in mid-channel. Ground-water samples from the five water-table wells (59 samples) and four deeper wells (47 samples) were collected with a submersible pump. At least three well volumes of water were purged before sampling began. Ground-water samples from 20 domestic wells screened in the drift were collected in September 1990, and from May to June 1991. Of these wells, 17 were outside the Vermillion River Basin. Most (15) domestic wells were sampled twice, four were sampled three times, and one was sampled once, for a total of 43 samples from domestic wells.

Water temperature, pH, specific conductance, and dissolved-oxygen concentrations were measured at each site. Samples were filtered in the field, chemically preserved, and placed on ice in coolers for transport to the laboratory. Chilled samples were shipped to the U.S. Geological Survey National Water Quality laboratory in Arvada, Colorado, for analyses of major inorganic ions and nutrients. In this report, nitrate concentrations are given in mg/L (milligrams per liter) as nitrogen and assumed to be equal to combined nitrite-plus-nitrate concentrations because nitrite concentrations were commonly negligible. Nitrite was determined on a subset of the samples; the median nitrite concentration was less than 1 percent of the combined nitrite-plus-nitrate concentration for samples that had both nitrite and nitrate concentrations above the reporting limits. Triazine herbicide content was determined for 92 samples by an immunoassay technique. Major inorganic ions were determined only on samples collected in 1991. The results of all water-quality analyses are available in the National Water Information System (NWIS) computer data base of the U.S. Geological Survey and the STORET computer data base of the U.S. Environmental Protection Agency.

Quality control was effected by calculation of ion balances and by analysis of field duplicates and filter blanks, which accounted for more than 10 percent of the samples analyzed. The average ion imbalance was only 1.4 percent, and only two samples had imbalances greater than 5 percent. Analyses of field duplicates agreed to within an average of 2 percent for major dissolved constituents (calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, and silica). The minor constituents (nitrite, ammonia, Kjeldahl nitrogen, phosphorus, and fluoride), which were often in concentrations near the reporting limit, had larger imprecisions, ranging from about 10 to 30 percent. Analyses of filter blanks indicated no significant contamination by any constituent. Small amounts of calcium and alkalinity in the blanks indicated that the filter apparatus was not perfectly rinsed between samples, but the amount of potential contamination was trivial (about 0.5 percent) compared to the calcium and alkalinity values of the samples being collected.

Contributing areas

Water quality at a sampling point depends on the source factors contributing water-quality constituents along the flow path leading to the sampling point (fig. 2). For point sources, such as discharge from a waste-treatment plant into a river, the river is clearly the primary flow path between the source and a downstream sampling point. For spatially distributed sources, the flow path between source factors and sampling points may not be readily apparent. The relation of spatially distributed sources to water quality at a sampling point requires the concept of a contributing area, which is defined in this report as that area of land or aquifer (as projected onto a horizontal plane) that contributes water to a sampling point. Water quality at a sampling point may then be related to the spatially distributed source factors that are present within the contributing area for that sampling point.

Contributing areas for surface-water sampling points were assumed to be the upstream subbasins. A subbasin comprises the area that contributes overland flow to a stream. No data were available to delineate the area of aquifer that contributes ground water to the stream in each subbasin. This aquifer area was assumed to be the same as the subbasin area, although this assumption may not be valid, especially for the smaller tributaries.

Contributing areas for ground-water samples were arbitrarily assumed to be a sector spanning a 30-degree arc and extending upgradient from the well to a distance corresponding to a 10-year horizontal ground-water-travel time (fig. 4). This distance was calculated from the estimated pumping rate of each well, the magnitude and direction of the horizontal hydraulic gradient at the well, and the aquifer transmissivity and porosity (Bear, 1979). A 10-year travel time was chosen partly because this time period encompasses the age of the land-use data, which were from 1984. The choice of a 30-degree arc to span the sector was arbitrary, but should account for some variability or uncertainty in the direction of ground-water flow near each well. The orientation of the sector upgradient from the well allowed knowledge of ground-water-flow directions to be incorporated in delineating contributing areas. Other studies have chosen circular contributing areas (buffer zones) of a fixed radius centered around each well (Vowinkel and Battaglin, 1989; Almendinger, 1991), which ignore information concerning ground-water flow directions and travel times. The previous investigation in Dakota County that used circular contributing areas for each well (Almendinger, 1991), however, produced results similar to those in this report, and thus the choice of the shape of the contributing area was not critical.

Physical factors

Geographic information system software was used to estimate the percent coverage of selected source factors, including agricultural land, Quaternary deposits, and bedrock, in each contributing area. Land-use data as of 1984 were obtained in digital form from the Minnesota Land Management Information Center. Information on the Quaternary deposits and bedrock was digitized by Dakota County personnel from 1:100,000-scale maps in the Dakota County geologic atlas (Balaban and Hobbs, 1990).

The transport factors examined were soil-leaching potential and water-table depth. Soil types in Dakota County were rated according to the soil-leaching potential, which is a measure of the likelihood that chemicals could be leached through the soil layer. For this study, the soil layer is defined as being the topmost 60 inches of unconsolidated material. The U.S. Department of Agriculture Soil Conservation Service rates the soil-leaching potential by a method that depends on the combined effects of soil permeability,

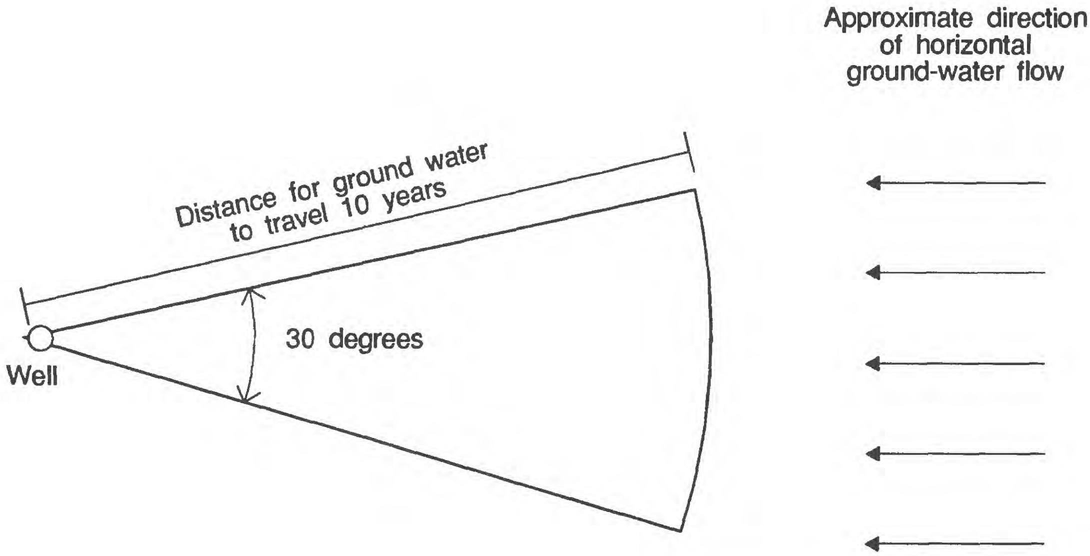


Figure 4.--Plan view of assumed contributing area for a well.

land-surface slope, depth to the seasonal high water table (which may include perched water), and organic matter content of the upper soil (Soil Conservation Service, 1992). Each soil series may be scored according to soil-leaching potential on a 3-point scale. A score of 1 corresponds to a large soil-leaching potential, 2 to a moderate soil-leaching potential, and 3 to a small soil-leaching potential. Soil series are grouped into soil associations, and each soil association in Dakota County was assigned an average soil-leaching potential score weighted by the percent areal coverage of the soil series within that soil association. Each contributing area was then assigned an average soil-leaching potential score weighted by the percent areal coverage of soil associations within that contributing area as determined by planimetry. Each contributing area was categorized as having a large, medium, or small soil-leaching potential, according to the weighted average soil-leaching potential score. A large soil-leaching potential corresponds to a weighted average score between 1 and 1.67, medium to a score between 1.68 and 2.33, and small to a score between 2.34 and 3.

A map of water-table depth in Dakota County was constructed by subtracting the water-table altitude mapped originally at 1:125,000 (Balaban and Hobbs, 1990) from land-surface altitude mapped originally at 1:62,500 on U.S. Geological Survey topographic quadrangles (L.C. Trotta, U.S. Geological Survey, St. Paul, Minn., written commun., 1990). This map of water-table depth was used to estimate the water-table depths at the 20 domestic wells. Water-table depths at the five Vermillion River sites were determined from the water-table wells there.

Acknowledgments

The help of landowners who permitted sampling of well water is gratefully acknowledged. The Soil Conservation Service provide instruction and literature on the method of calculating soil-leaching potentials. The Metropolitan Waste Control Commission provided data on wastewater discharges. Both Dakota County and the Minnesota Geological Survey provided data in digitized or mapped form.

Hydrology

A brief overview of the surface-water and ground-water hydrology in Dakota County provides the basis for understanding the flow paths of water and associated chemical constituents.

Surface Water

Dakota County receives about 28 inches of precipitation each year, of which about 23 inches is returned to the atmosphere by evapotranspiration (Norvitch and others, 1973). The remaining 5 inches of water, the climatic moisture surplus (Sellers, 1965), moves to streams either by overland flow or by ground-water flow and becomes runoff.

Streamflow comprises both overland flow and baseflow. Baseflow presumably is derived primarily from ground water that discharges into the channel. The flow of the Vermillion River tends to be stable because of the large baseflow component, which has gradual seasonal trends. Rain or snowmelt can produce enough overland flow, however, to cause occasional peaks in flow that are in excess of the baseflow component (fig. 5).

The average streamflow of the Vermillion River at site 2 (fig. 3) was 53.4 ft^3/s (cubic feet per second) for 18 years of record (1974-91). Long-term data are not available for the other four sampling sites. The 18-year average streamflow at site 2 corresponds to an average annual runoff of about 5.2 inches, which is similar to the estimated annual climatic moisture surplus of 5 inches (Norvitch and others, 1973). During water year 1990, however, the annual mean streamflow at site 2 was only 41.5 ft^3/s, about 78 percent of the 18-year average streamflow and corresponding to a runoff of about 4.1 inches (table 2). Runoff estimated at the other Vermillion River sites during water year 1990 ranged from 0.5 inches at site 4 to 5.6 inches at site 3 (table 2). Differences in runoff among nearby basins may result from differences in precipitation, evapotranspiration, or interbasin transfers of ground water. In particular, a basin with less runoff than surrounding basins may be losing ground water to those basins.

Ground Water

Ground water moving from upland recharge areas to discharge points such as streams and other surface-water bodies typically has a large horizontal component of flow. In a surficial aquifer near a stream, if the water table is higher than a stream, then shallow ground water is moving to the stream (fig. 2). If the water table is lower than the stream, then stream water may be moving into the aquifer, and ground water is moving to some other point of discharge. The direction of ground-water flow can change depending on fluctuations in the water-table and stream levels. Comparison of stream levels with the water levels in the water-table wells at the five Vermillion River sites (fig. 6) showed that the water table was usually higher than or equal to the stream level at sites 1, 2, and 3, and consequently shallow ground water was usually moving to the stream at these sites. The water table was usually lower than the stream level at sites 4 and 5, and consequently shallow ground water was usually not discharging into the stream at these sites but was moving to some other point of discharge. The stream at site 4 was usually dry, and the water table was below the dry stream bed.

Ground water also can have a vertical component of flow. Beneath recharge areas ground water moves downward, and beneath discharge points ground water moves upward (fig. 2). Comparison of water levels in water-table wells and deeper wells can indicate whether ground-water flow is upward or downward (Winter, 1984). If a water-table well has a higher water level than that in an adjacent deeper well, then some ground water is moving downward. If a water-table well has a lower water level than that in a deeper well, then some ground water is moving upward. The direction of vertical ground-water flow can change depending on fluctuations of the water table relative to water level in the deeper well. Comparison of water levels in water-table wells and deeper wells at sites 1-4 allowed estimation of the direction of vertical ground-water flow during 6 to 12 sampling trips in 1990-91 (fig. 6). Ground water was usually moving upward at site 3 between the deeper well (about 30 feet below the water table) and the water table. This deeper ground water may discharge into the stream (South Fork Vermillion River) at site 3, as does the shallow ground water. Ground water was usually moving downward at site 4 between the water table and the deeper well. Ground water usually does not discharge into the stream at site 4, but moves toward some other point of discharge. At sites 1 and 2 the water levels in the water table wells and deeper wells showed no consistent pattern, indicating that vertical ground-water flow between the water table and the deeper wells was neither consistently upward nor downward. The deeper wells were screened about 10 feet below the water table at site 1 and about 30 feet below the water table at site 2. Downward-moving deeper ground water can bypass the river at sites 1 and 2 and flow to some other point of discharge (for illustration, see deeper ground-water flow path, fig. 2).

Site 5 differed from the rest because the water table about 50 horizontal feet from the Vermillion River is more than 40 feet below the bottom of the channel,

Table 2.--Summary of subbasin and streamflow data from five sites in the Vermillion River Basin, Dakota County, Minnesota, 1990-91

[streamflow in cubic feet per second]

Location[1]	Subbasin area, square miles	Streamflows measured during sample trips, 1990-91: Minimum (month/year)	Median	Maximum (month/year)	Number of observations	For 1990 water year: Estimated annual mean streamflow	Estimated annual runoff, inches
Site 1 tributary	31	1.2 (February 1991)	15	63 (June 1990)	10	[2]7.6	3.4
Site 2 main stem	138	19 (February 1990)	47	149 (June 1990)	11	[3]41.5	4.1
Site 3 tributary	32	5.9 (January 1990)	12	51 (March 1990)	11	[4]13.3	5.6
Site 4 tributary	6	0 (usually)	0	1 (March 1990)	12	[2].2	.5
Site 5 main stem	193	25 (January 1990	70	183 (March 1990)	9	[4]58.5	4.1

[1] Site locations shown in figure 3.

[2] Calculated from correlation of instantaneous streamflow measurements to streamflow at site 2.

[3] Calculated from continuous stage data and stage-streamflow relation.

[4] Calculated from continuous stage data and stage-streamflow data during ice-free months, and by correlation of instantaneous streamflow measurements to streamflow at site 2 during winter months.

indicating that an unsaturated zone may exist at some depth below the channel. The level of the water table relative to the Vermillion River in the vicinity of site 5 may be related to the proximity of the deep Mississippi River trench less than two miles to the northeast. Nearby buried bedrock valleys filled with drift may lower the water table by being permeable conduits leading to the Mississippi River trench. The vertical movement of ground water at site 5 could not be determined with certainty because a deeper well was not installed below the water table. Ground water is probably not moving upward, however, because the site is not a point of ground-water discharge. Site 5 is more likely an area of ground-water recharge from water seeping out of the Vermillion River into the surficial aquifer, and the ground-water flow probably has a downward component, in addition to a horizontal component leading toward the Mississippi River.

Water Quality

The water quality measured at a site varies among sample types and with time. These variations are important considerations in obtaining representative water-quality values for each site. Differences among sample types and variability with time were examined with respect to specific conductance, nitrate, and triazines.

Differences Among Sample Types

Water quality differed among surface-water, shallow ground-water, and deeper ground-water sample types collected at Vermillion River sites 1-4. The null hypothesis that the specific conductance values (table 3) and nitrate concentrations (table 4) were the same in these three sample types was rejected at the probability $P = 0.01$ level with the Kruskal-Wallis test applied separately to each of these four sites. Median specific conductance values and nitrate concentrations were larger in shallow ground water than in deeper ground water, except for nitrate concentrations at site 4. Differences between the quality of shallow ground water and surface water were not so consistent among sites. For example, median specific conductance values in shallow ground water were larger than those in

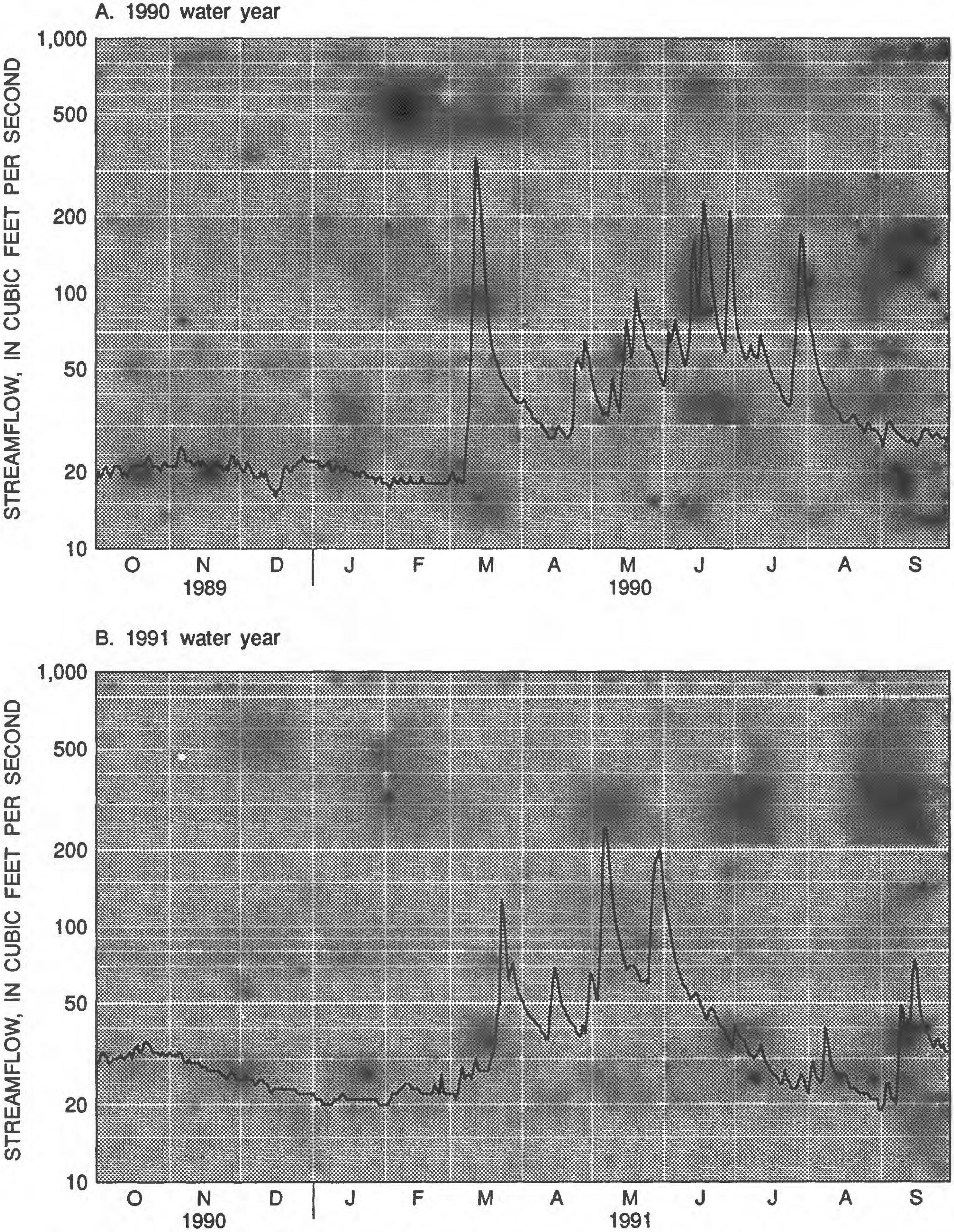


Figure 5.--Daily average streamflow of the Vermillion River at site 2 during (A) 1990, and (B) 1991 water years, Dakota County, Minnesota (U.S. Geological Survey station 05345000, Vermillion River near Empire, Minnesota).

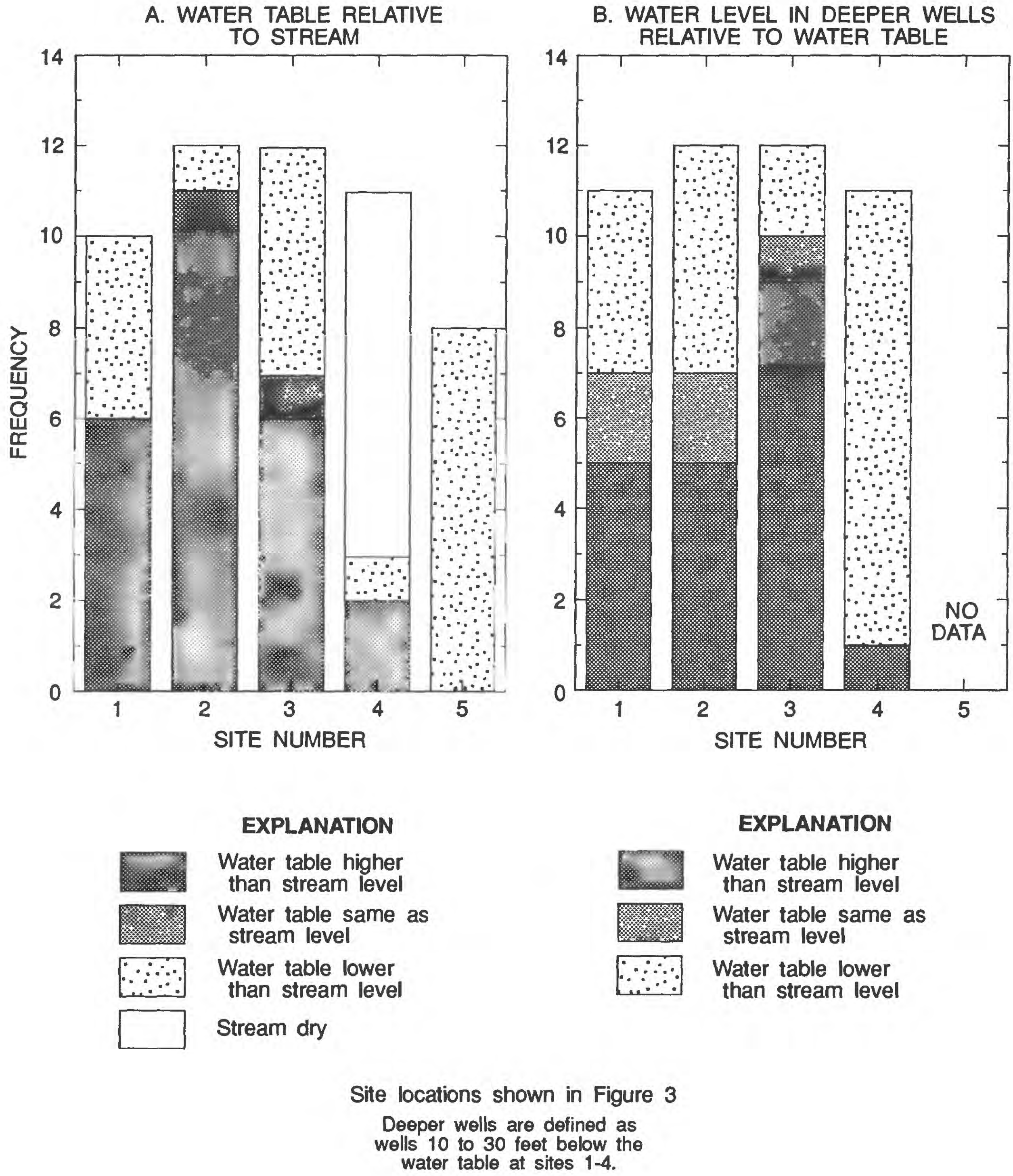


Figure 6.--Frequency of relative water-level measurements for (A) water table relative to stream, and (B) deeper wells relative to water table for five sites in the Vermillion River Basin, Minnesota during 6 to 12 sampling trips in 1990-91.

Table 3.--Specific conductance values in water for three sample types collected at five sampling sites in the Vermillion River Basin, Minnesota, 1990-91

[values in microsiemens per centimeter at 25 degrees Celsius; n, number of measurements; min, minimum; med, median; max, maximum; IQR, interquartile range, the difference between the upper and lower quartiles; upper quartile, the value greater than or equal to 75 percent of analyses; lower quartile, the value greater than or equal to 25 percent of analyses; n/a, not applicable; --, no data; **, significant at the 0.01 level; ns, not significant at the probability P = 0.01 level; statistical significance based on Kruskal-Wallis test]

	Sample type															Statistical significance of differences among sample types
	Surface water					Shallow ground water					Deeper ground water					
Site	n	min	med	max	IQR	n	min	med	max	IQR	n	min	med	max	IQR	
1	11	402	594	632	185	12	787	1090	1570	578	12	567	605	631	19	**
2	12	482	759	1060	193	12	521	699	749	74	12	311	505	662	30	**
3	12	446	500	544	44	12	534	584	595	29	11	473	501	518	23	**
4	3	430	654	694	n/a	12	372	595	855	166	12	366	377	406	23	**
5	11	547	709	883	115	11	572	722	952	253	--	--	--	--	--	ns
Average IQR values:					134					220					24	

Table 4.--Nitrate concentrations in water for three sample types collected at five sampling sites in the Vermillion River Basin, Minnesota, 1990-91

[values in milligrams per liter as nitrogen; n, number of measurements; min, minimum; med, median; max, maximum; IQR, interquartile range, the difference between the upper and lower quartiles; upper quartile, the value greater than or equal to 75 percent of analyses; lower quartile, the value greater than or equal to 25 percent of analyses; n/a, not applicable; <, less than; --, no data; **, significant at the 0.01 level; ns, not significant at the probability P = 0.01 level; statistical significance based on Kruskal-Wallis test]

	Sample type															Statistical significance of differences among sample types
	Surface water					Shallow ground water					Deeper ground water					
Site	n	min	med	max	IQR	n	min	med	max	IQR	n	min	med	max	IQR	
1	11	0.5	1.1	4.0	0.9	12	<0.1	0.3	1.6	0.5	12	<0.1	<0.1	<0.1	0.0	**
2	12	3.1	5.0	10.0	.4	12	5.5	8.6	25.0	3.9	12	<.1	<.1	<.1	0	**
3	12	2.7	4.8	5.9	1.3	12	2.1	7.6	11.0	4.7	11	<.1	<.1	<.1	0	**
4	3	<.1	<.1	2.0	n/a	12	.5	3.2	11.0	1.9	12	1.0	4.7	5.0	.4	**
5	11	3.9	5.5	7.4	1.6	11	2.3	5.2	9.6	3.9	--	--	--	--	--	ns
Average IQR values:					1.0					3.0					.1	

surface water at sites 1 and 3, and smaller at sites 2 and 4 (table 3). Median nitrate concentrations in shallow ground water were larger than those in surface water at sites 2-4, and smaller at site 1 (table 4).

In contrast, water quality was not significantly different between surface-water and shallow ground-water sample types at site 5 (tables 3 and 4). The water quality of shallow ground water and surface water may be similar at site 5 because movement of surface water into the aquifer may be a primary source of shallow ground water at this site. The shallow ground water from site 5 was excluded from analyses relating water quality to source factors because of the dominating influence of surface-water quality at this site.

Triazine herbicide content in 49 filtered water samples from the Vermillion River sites was measured with an immunoassay technique that categorizes the triazine concentration into the following ranges: not detected, less than 0.1 μg/L (micrograms per liter); small, from 0.1 to 0.25 μg/L; moderate, from greater than 0.25 to 2 μg/L; and large, greater than 2 μg/L. The U.S. Environmental Protection Agency proposed maximum contaminant level for atrazine, one of the triazine herbicides, is 3 μg/L (U.S. Environmental Protection Agency, 1989). None of the samples had a triazine concentration greater than 2 μg/L. Of 18 surface water samples, nine had moderate, six had low, and three had non-detectable amounts of triazines. Of 18 shallow ground water samples, two had moderate, four had low, and 12 had non-detectable amounts of triazines. Triazines were not detected in any of the 13 samples of deeper ground water.

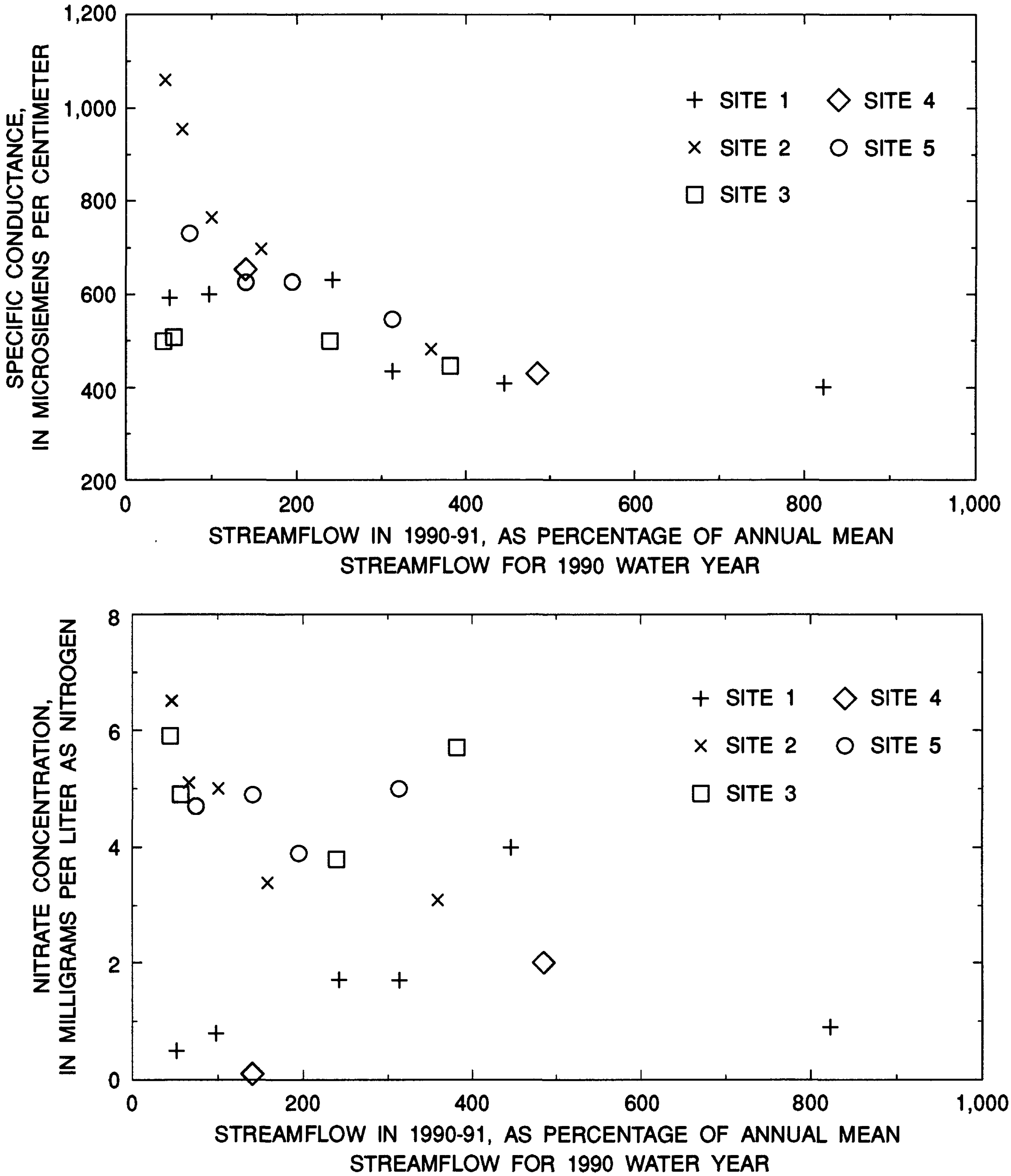
Water-quality differences among sample types may arise because of differences in the contributing areas. The surface-water sample integrates contributions from overland flow and ground-water discharge in the upstream subbasin, the shallow ground-water sample is from the surficial aquifer immediately upgradient from the site, and the deeper ground-water sample could have originated far from the sampling site. For example, nitrate was not detected in water from the deeper wells at sites 1-3 (table 4) despite the proximity of agricultural land, which presumably is the source of the nitrates found in the shallow ground water and surface water. The ground-water flow paths intercepted by the deeper well screen may have originated beneath a point on the land surface where nitrate fertilizers were not applied, or nitrates may not have had time to reach the deeper well because of the length of the flow paths, or bacteria may have denitrified the water along the flow paths.

Variability with Time

Variability of water quality with time is related to sample type. A measure of variability with time is the interquartile range. The interquartile range is the difference between the upper quartile (the value equal to or greater than 75 percent of analyses) and the lower quartile (the value equal to or greater than 25 percent of analyses). The averages of interquartile ranges of both specific conductance values (table 3) and nitrate concentrations (table 4) are smaller for deeper ground water than for either surface water or shallow ground water at the five Vermillion River sites. Therefore the variability of these selected water-quality constituents is smaller for deeper ground water than for either surface water or shallow ground water. The quality of deeper ground water may not vary much because it is moving too slowly to change appreciably at that point during the period of sampling. Alternatively, the small variability may result from chemical homogenization by dispersive mixing along long ground-water flow paths deeper in the aquifer.

Stream-water quality varies with time as streamflow changes. Hem (1985) indicates that specific conductance of stream water typically is related inversely to streamflow, which varies with the season. Specific conductance values tended to have an inverse relation with streamflow at the five Vermillion River sites (fig. 7). Streamflow in the Vermillion River Basin was greater during spring and summer months (March-August) in 1990-91 (fig. 5), than during autumn and winter months (September-February) and thus in general the stream water most sites had slightly smaller values of specific conductance in spring and summer than during autumn and winter. Nitrate concentrations were not so simply related to streamflow, and more samples than were collected for this study may be needed to distinguish trends at any one site.

Triazine content of surface-water samples varied seasonally with the streamflow. Of the nine surface-water samples with moderate triazine content, eight were collected during spring, and six were collected during flows greater than the annual mean streamflow. Triazines apparently moved to the river with overland runoff during high flow conditions. Squillace and Thurman (1992) found similar results in the Cedar River Basin in northeastern Iowa, where 94 percent of the river load of atrazine originated from overland flow and only 6 percent came from ground-water discharge into the river.



Site locations shown in Figure 3

Figure 7.--Relation of specific conductance values and nitrate concentrations in stream water to streamflow in the Vermillion River Basin, Minnesota, 1990-91.

Relation of Selected Water-Quality Constituents to Selected Physical Factors

The purpose of this section of the report is to relate water quality to selected physical factors that affect chemical constituents in water at a sampling point.

Source Factors

Source factors are categorized in this report as either point sources or spatially distributed sources.

Point sources

The only point source examined was a waste-water treatment plant on the main stem of the Vermillion River about 2.5 river miles upstream from site 2 and about 13 river miles upstream from site 5 (fig. 3). Monthly average discharge and nitrate-concentration data (Melba Hensel, Metropolitan Waste Control Commission, written commun., 1991) were multiplied to obtain a monthly average nitrate loading from January 1990 through June 1991. Nitrate load from the waste-water discharge accounted for an average of 92 percent (n = 11) of the nitrate load measured in stream water at site 2, and 60 percent (n = 9) of the nitrate load measured in stream water at site 5. The waste-water discharge apparently was the primary source of nitrates in the main stem of the Vermillion River downstream from the point of discharge from January 1990 through June 1991. Because the nitrate concentrations of surface-water samples from sites 2 and 5 were so influenced by the waste-water discharge, these samples were excluded from analyses examining the relations between nitrate concentrations and other physical factors.

Spatially distributed sources

In the following analyses, the median values of water-quality constituents at each sampling point were used as the measure of water quality in examining bivariate relations between selected water-quality constituents and selected physical factors. The use of median values, rather than the raw data, avoids over-representation of sampling points where more samples were collected than at other sampling points. Overlapping contributing areas could cause over-representation of physical factors within the area of overlap, because the same set of physical factors there would be included more than once in the statistical analyses. In particular, the method of estimating contributing areas for ground-water sampling points does not take vertical gradients into account, and consequently the estimated contributing areas for the water-table wells and deeper wells are exactly overlapping at each of the Vermillion River sites 1-4. Data from either the water-table wells or the deeper wells were excluded from certain analyses to remove the overpresentation caused by overlapping contributing areas. Data from the water-table wells were used where the ground-water flow paths between the source factor (such as agricultural land or Quaternary deposits) and the sampling point had predominantly horizontal and downward components. Data from the deeper wells were used where the ground-water flow paths between the source factor (such as bedrock) and the sampling point had some upward component.

Agricultural land

Agricultural practices can introduce pesticides and fertilizers into surface and ground waters (Freeze and Cherry, 1979; Goolsby and others, 1991). Most of the contributing areas for sampling points in the present study were classified as having predominantly agricultural land. Surface-water sampling points at Vermillion River sites 2 and 5 and the water-table well at site 5 were excluded from analysis because of influence from the waste-water treatment plant; deeper wells at Vermillion River sites 1-4 were excluded from analysis because their contributing areas overlapped with those of the water-table wells at the same sites. Fifteen of the remaining 27 sampling points had equal to or greater than 90 percent agricultural land in the contributing areas, and seven had between 50 and 90 percent.

Nitrate concentrations in water were related to the percentage of agricultural land in the contributing area (fig. 8). Sampling points with large percentages (equal to or greater than 75 percent) of agricultural land can have larger nitrate concentrations (median 3.6 mg/L as nitrogen) than do sampling points with a smaller percentage of agricultural land (median below the detection limit of 0.1 mg/L as nitrogen). Many sampling points, however, had small nitrate concentrations despite having a large percentage of agricultural land in the contributing area. Concentrations of dissolved Kjeldahl nitrogen and dissolved phosphorus appeared to be related to agricultural land in the same way that nitrate concentrations were. Specific conductance,

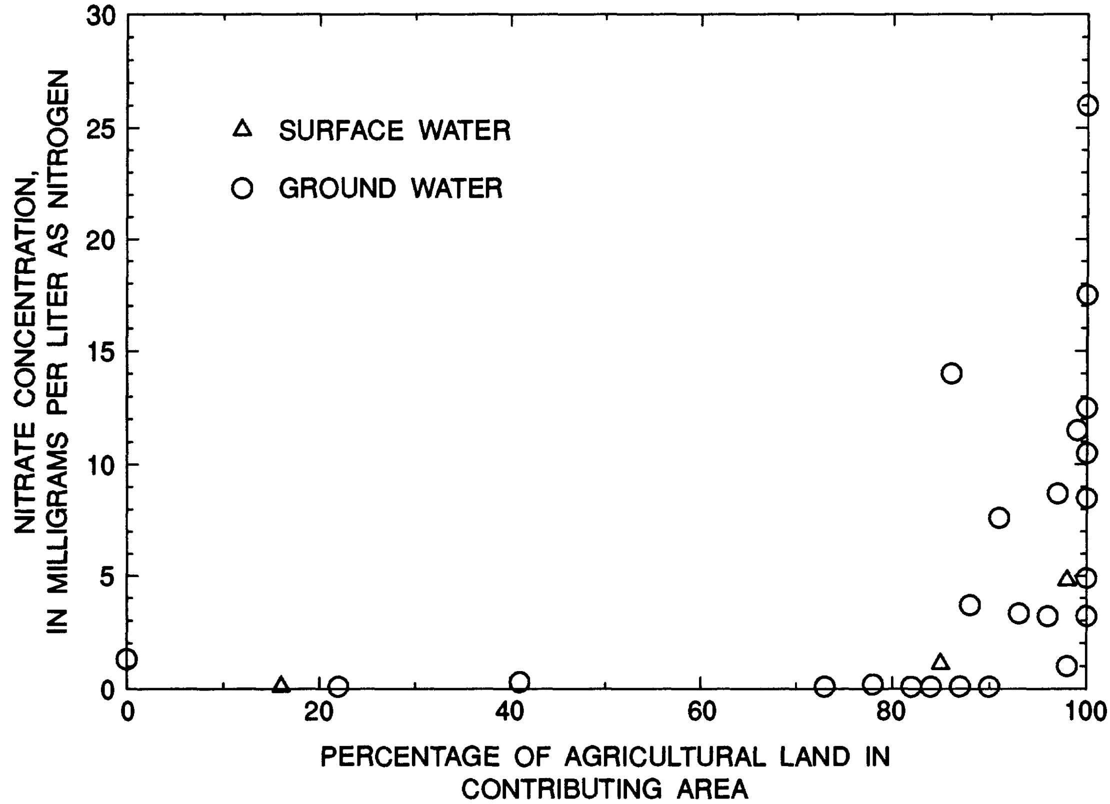


Figure 8.--Relation of median nitrate concentrations in water to percentages of agricultural land in contributing area of sampling points in Dakota County, Minnesota, 1990-91.

chloride concentration, and other water-quality constituents showed no apparent relation to percent coverage of agricultural land in the contributing areas.

Triazine herbicides were detected at all five of the surface-water sampling points. Areal coverage of agricultural land in the contributing subbasins ranged from 16 to 98 percent; four of the five subbasins had 85 percent or greater. Triazine was detected in reportable concentrations at five of the ground-water sampling points, and agricultural land accounted for more than 90 percent coverage of the contributing area for four of these sampling points.

Quaternary deposits

Quaternary deposits are a source of dissolved minerals in the water. Unweathered glacial deposits of the Des Moines ice lobe are calcareous, whereas other glacial deposits in Dakota County typically are not calcareous. Three of the subbasins (contributing areas for surface-water sampling points) in this study have more than 50 percent coverage by Des Moines lobe deposits, and two subbasins have less than 50 percent coverage. Contributing areas of 13 of the 25 ground-water sampling points have more than 80 percent coverage by Des Moines lobe deposits, and 10 have less than 50 percent coverage. Deeper wells at Vermillion River sites 1-4 were excluded from the analysis because

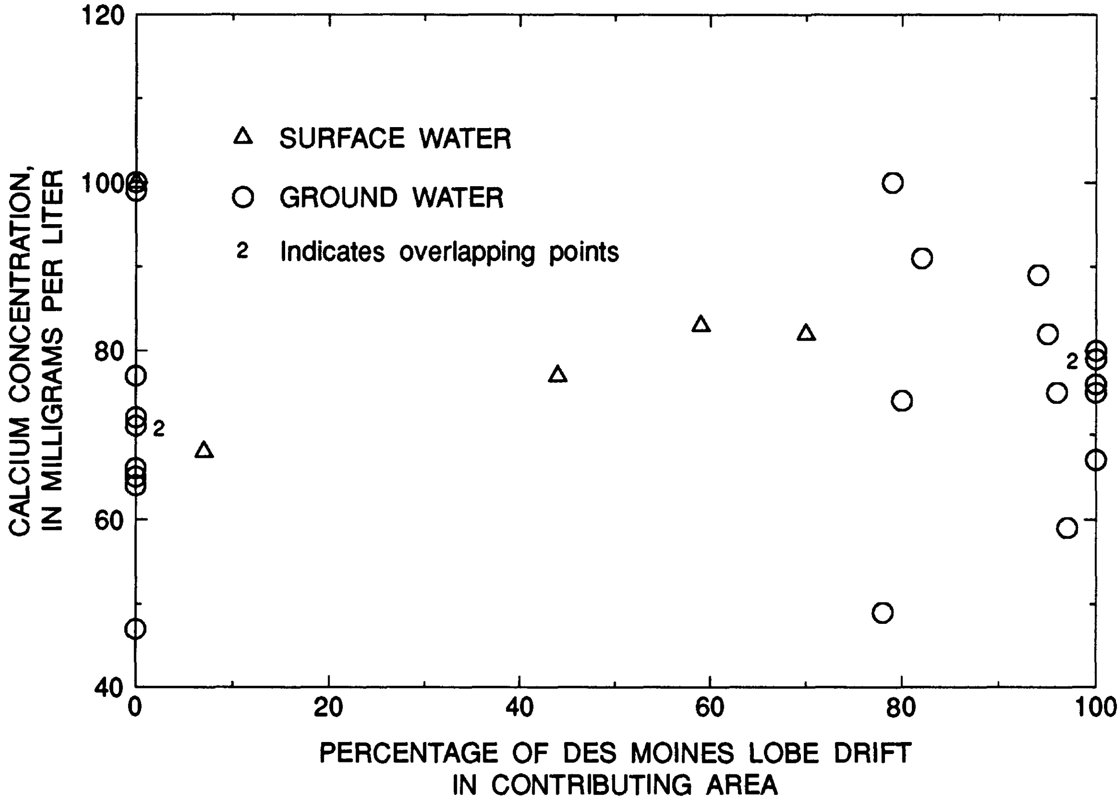


Figure 9.--Relation of median calcium concentrations in water to percentages of Des Moines lobe drift in contributing area of sampling points in Dakota County, Minnesota, 1990-91.

their contributing areas overlapped with those of the water-table wells at the same sites. One domestic well was excluded from the analysis because necessary data were not collected there.

Dissolution of carbonate minerals from calcareous deposits could result in elevated levels of dissolved calcium, magnesium, bicarbonate (alkalinity), and pH. No relation was apparent, however, between any of these water-quality constituents and the percent coverage of the contributing area by Des Moines lobe deposits. For example, the median concentrations of dissolved calcium at each sampling point ranged from 47 to 100 mg/L, and no trend in calcium concentrations with percentage of Des Moines lobe drift was evident (fig. 9). For some of the ground-water sampling points, the geology at the depth of the well screen may differ from the mapped Quaternary deposits at the land surface.

Bedrock

Bedrock can be a source of dissolved minerals in water and can affect the quality of surface water and ground water in the drift where ground water is moving upward from bedrock aquifers. Only sampling points with indication of upward-moving ground water in the contributing areas were included in the analysis. These were the surface-water sampling points from the Vermillion River sampling sites 1-5, and the deeper

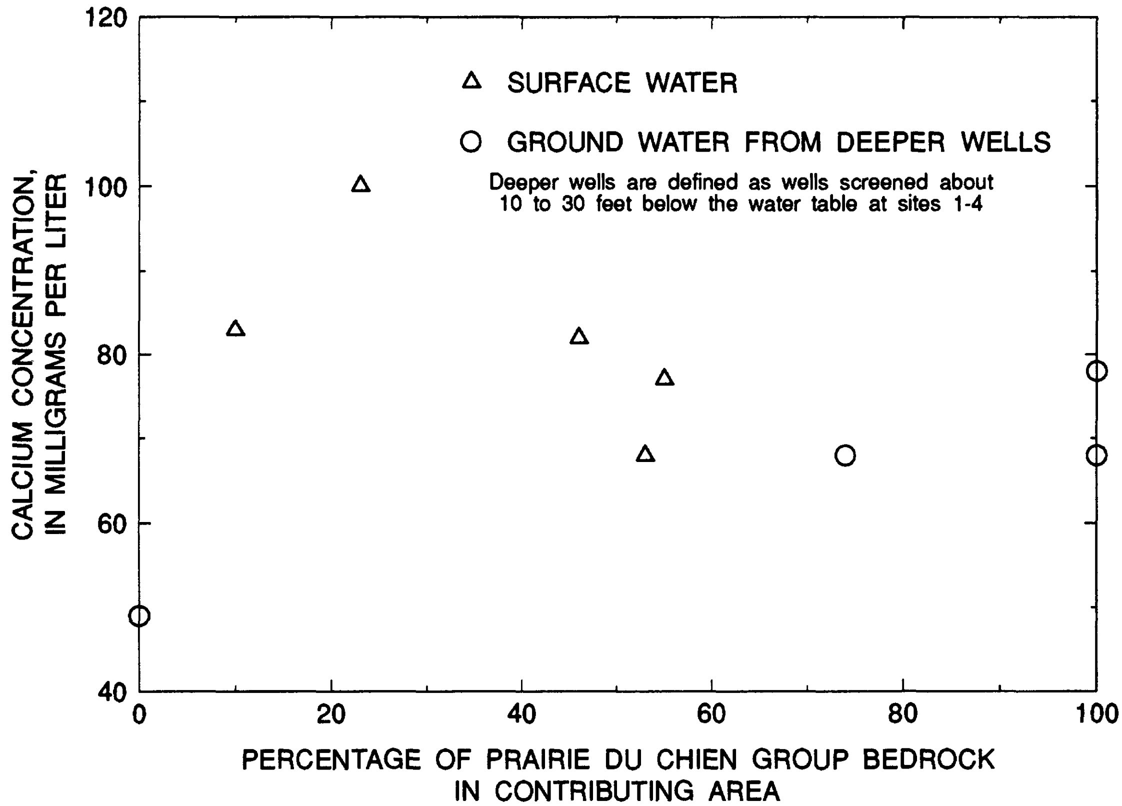


Figure 10.--Relation of median calcium concentrations in water to percentages of Prairie du Chien Group bedrock in contributing area of sampling points in the Vermillion River Basin, Minnesota, 1990-91.

wells at sites 1-4. Even for these sampling points, the upward movement of the ground water was determined just within the drift and demonstrates only the possibility of ground water moving upward from the bedrock.

Subbasins for the Vermillion River surface-water sampling points 2, 3, and 5 have about 50 percent coverage by subcrops of the Prairie du Chien Group. Subbasins for the Vermillion River surface-water sampling points 1 and 4 have more than 50 percent coverage by subcrops of the St. Peter Sandstone. Each of the contributing areas for the deeper ground-water sampling points at the Vermillion River sites 1-3 has over 70 percent coverage by subcrops of the Prairie du Chien Group.

Dissolution of calcite and dolomite in the Prairie du Chien Group could result in elevated levels of dissolved calcium, magnesium, bicarbonate, and pH. No relation was evident, however, between these water-quality constituents and percent coverage of Prairie du Chien Group in the contributing area. For example, the median concentrations of dissolved calcium at the sampling points were not proportional to coverage of the contributing area by subcrops of Prairie du Chien Group (fig. 10). Surface-water quality and ground-water quality at the Vermillion River sites did not appear to be controlled by the type of bedrock subcrop in the contributing area.

Transport Factors

Transport factors affect the direction and rate of the movement of chemical constituents from a source factor to the sampling point. Because transport factors do not add chemical constituents to the water, transport factors alone cannot be causally related to chemical constituents found in the water at the sampling point. Instead, examining transport factors may help explain residual data variability in a known relation between a source factor and water quality. In this study, the most likely relation between a source factor and water quality in Dakota County was between agricultural land and nitrate concentrations in ground water. Consequently, the effect of transport factors on this relation was analyzed. This analysis includes 24 ground-water sampling points: the 20 domestic wells and the water-table wells at Vermillion River sites 1-4. The water-table well at site 5 was excluded because of possible influence from surface water and the waste-water treatment plant, and the deeper wells at sites 1-4 were excluded because their contributing areas overlapped those of the corresponding water-table wells.

Soil-leaching potential

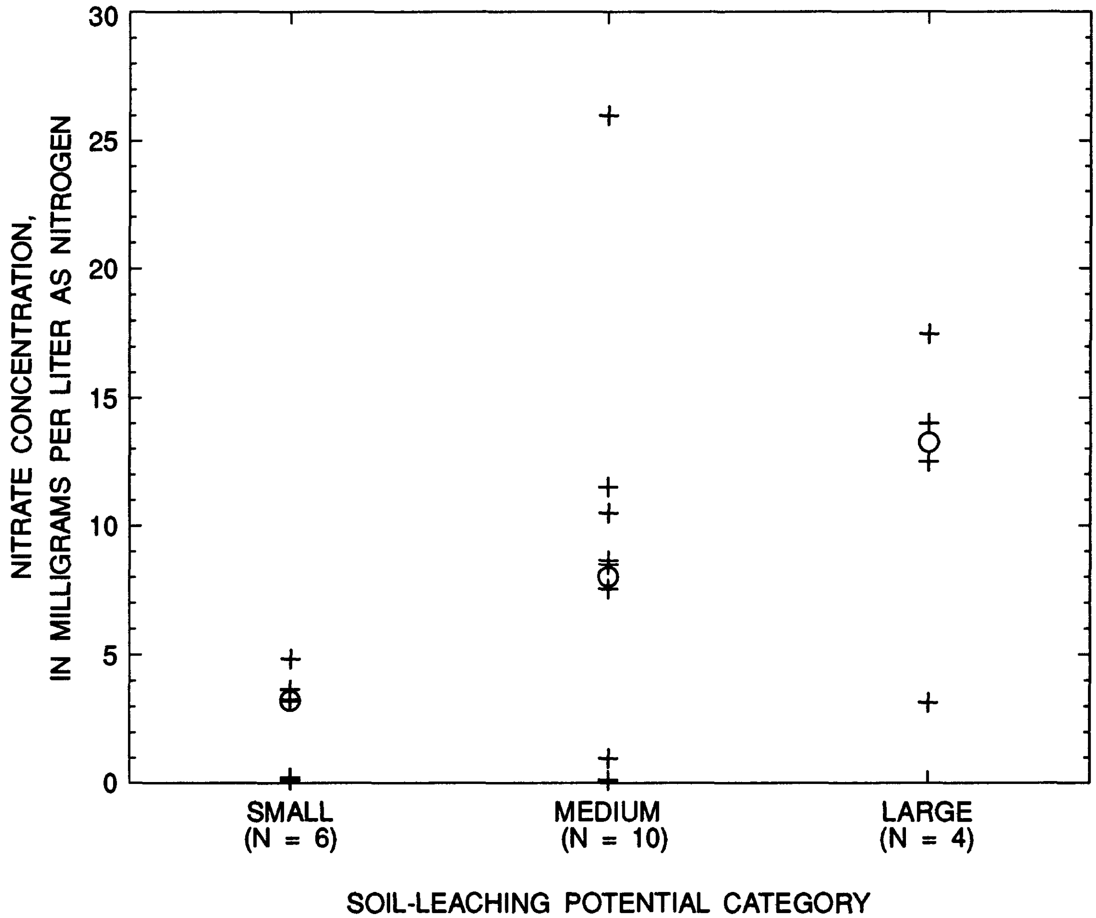
Soil composition and surface slope affect the leaching of dissolved constituents from the soil layer. Soil-leaching potentials of soil types in Dakota County were categorized and scored according to Soil Conservation Service (1992) procedures, and are based on characteristics of only the uppermost 60 inches of unconsolidated materials. The contributing areas for five of the ground-water sampling points had large soil-leaching potentials, 13 had medium soil-leaching potentials, and seven had small soil-leaching potentials.

Nitrate concentrations in ground water were related to soil-leaching potential at sampling points with large areal coverage (equal to or greater than 75 percent) of agricultural land in the contributing areas (fig. 11). The relation was not strong, howêver: the null hypothesis that sites with different soil-leaching potential categories had the same nitrate concentrations in ground water was rejected by the Kruskal-Wallis test at only the probability $P = 0.15$ level. Sampling points with small soil-leaching potential had relatively small nitrate concentrations (median 3.2 mg/L as nitrogen) in the ground water. A small soil-leaching potential indicates reduced or retarded infiltration and percolation, and thus the transport of nitrates from the land surface to the water table is reduced or at least delayed. Sampling points with large soil-leaching potential had large nitrate concentrations (median 13.2 mg/L as nitrogen) in the ground water because transport of nitrates from the land surface to the water table is relatively unhindered. Sampling points with medium soil-leaching potential had intermediate nitrate concentrations (median 7.6 mg/L as nitrogen) in the ground water.

Water-table depth

Water-table depth affects the travel time of water and dissolved constituents through the unsaturated zone. For the 25 ground-water sampling points in this study (table 1), water-table depth is greater than 100 feet for seven, between 50 and 100 feet for twelve, and less than 50 feet for six. A large water-table depth should result in a long travel time for water percolating from the land surface to the water table, all other transport factors being equal. A long travel time allows time for transformation processes, such as denitrification, to reduce the concentration of certain dissolved constituents, such as nitrate. Thus nitrate concentrations in ground water conceivably could be inversely related to water-table depth.

Nitrate concentrations in ground water, however, apparently were not related to water-table depth at sites with large areal coverage (equal to or greater than 75 percent) of agricultural land in the contributing area (fig. 12). Possibly other factors are more important than water-table depth in controlling the travel time of percolating water. The texture and moisture content of the material that composes the unsaturated zone are factors that are particularly important in controlling the travel time of percolating water. The relation shown in the previous section between nitrate concentrations in ground water and soil-leaching potential, which typically is proportional to the coarseness of the soil texture, indicates that texture is an important control on the travel time of percolating water and dissolved nitrates through the unsaturated zone.



EXPLANATION

+ Median for each sampling point with agricultural land equal to or greater than 75 percent

O Median of the medians within each soil-leaching potential category

For area-weighted soil-leaching potential:

Small	3.00 > SLP > 2.34
Medium	2.33 > SLP > 1.68
Large	1.67 > SLP > 1.00

Figure 11.--Relation of nitrate concentrations in ground water to soil-leaching potential category for sampling points with equal to or greater than 75 percent agricultural land in contributing area of sampling points in Dakota County, Minnesota, 1990-91.

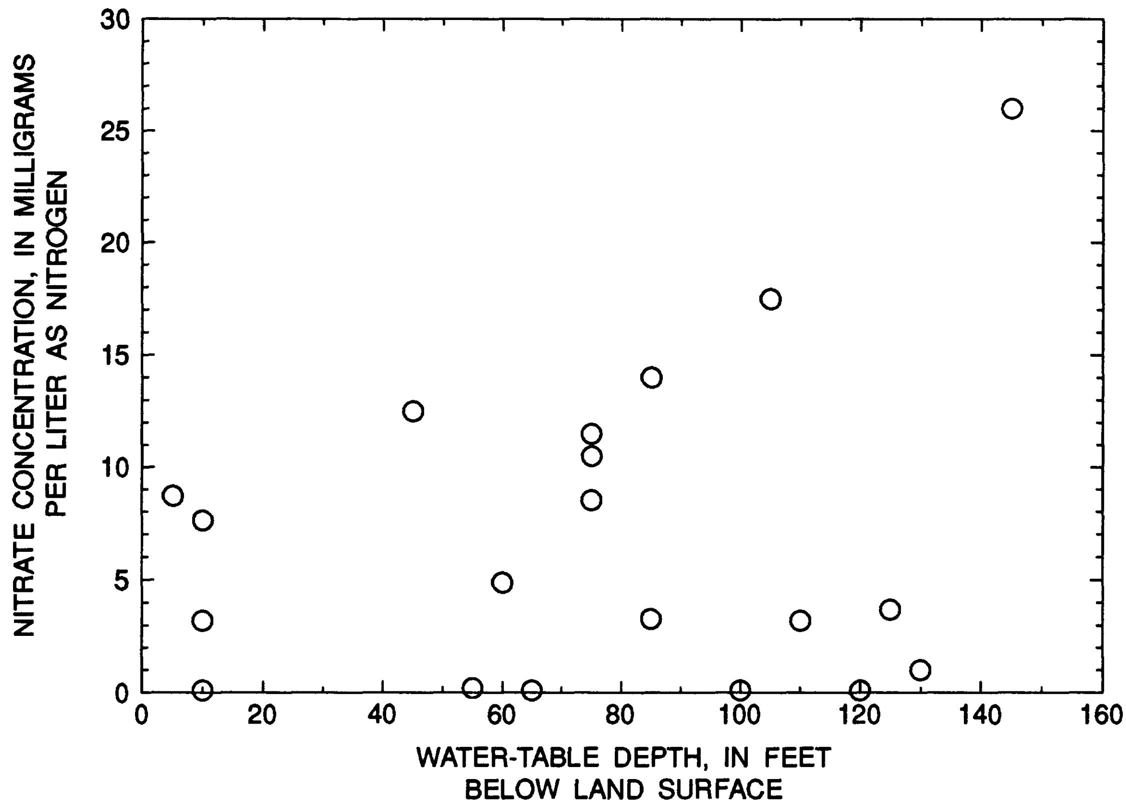


Figure 12.--Relation of nitrate concentrations in ground water to water-table depths for sites with equal to or greater than 75 percent agricultural land in contributing area of sampling points in Dakota County, Minnesota, 1990-91.

Summary

State and local officials in Minnesota are concerned about the potential effects of agricultural chemicals on water quality in Dakota County. Drift aquifers in Dakota County are susceptible to infiltrating contaminants such as fertilizers and pesticides. These contaminants can also move to streams, such as those in the Vermillion River Basin in central Dakota County. Effective management of water resources requires knowledge about hydrology and physical factors that can affect water quality. The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources, the Legislative Commission on Minnesota Resources, and the Dakota County Soil and Water Conservation District, began a study in 1989 to investigate water quality in Dakota County. As part of this study, the purpose of this report is to investigate the hydrology of the Vermillion River Basin and to relate selected water-quality constituents to selected physical factors in Dakota County, both within and beyond the Vermillion River Basin. Physical factors examined were waste-water discharge, agricultural land, Quaternary deposits, bedrock, soil-leaching potential, and water-table depth.

Streamflow was measured periodically at two sites on the mainstem Vermillion River and at three sites on tributaries near their mouths; these five sites are referred to as the Vermillion River sites. A water-table well was constructed within about 50 horizontal feet of the stream at each of the five sites, and a deeper well was screened about 10 to 30 feet below the water table at four of the sites. Water levels in these nine wells were used to determine whether ground water was moving toward or away from the stream at these sites. Surface-water samples were collected at the five Vermillion River sites. Ground-water samples were collected from 29 drift wells, 9 of which were those at the five Vermillion River sites and 20 of which were domestic wells. Seventeen of the domestic wells were located outside the Vermillion River Basin. A total of 198 water samples were collected in 1990-91 and analyzed for nutrients; selected samples were also analyzed for major inorganic ions and triazine herbicide content. Contributing areas for surface-water samples were assumed to be the upstream subbasin. Contributing areas for ground-water samples were assumed to be a sector spanning 30 degrees and extending upgradient from the well to a distance corresponding to a 10-year horizontal ground-water travel time. Physical factors inside these contributing areas were determined from existing mapped or digitized data.

Annual average streamflow of the Vermillion River near the middle of its basin was 41.5 cubic feet per second during the 1990 water year (October 1, 1989, through September 30, 1990), about 78 percent of the 18-year average. Shallow ground water at three sites in the Vermillion River Basin was moving toward the stream during at least half of the sampling trips to those sites in 1990-91. At one site in the lower portion of the basin and at another site along an intermittent tributary, however, water from the river and tributary (when flowing) can seep into the aquifer. Deeper ground water 10 to 30 feet below the water table was moving horizontally or downward at four of the sites during more than half of the sampling trips. This ground water may pass under the Vermillion River and discharge into the Mississippi River to the east.

Selected water-quality constituents typically differed among sample types at the Vermillion River sites. The quality of surface water from the streams, water from the water-table wells, and water from the deeper wells differed at sites 1-4. The most consistent difference was in nitrate concentrations at sites 1-3, where ground water moved to the stream during at least half of the sampling trips. At these sites, nitrate was not detected at the 0.1 milligrams per liter (mg/L) as nitrogen level in water from the deeper wells. In contrast, nitrates were present at these three sites in water from water-table wells (median values of 0.3, 8.6, and 7.6 mg/L as nitrogen for sites 1-3, respectively) and surface water (median values of 1.1, 5.0, and 4.8 mg/L as nitrogen for sites 1-3, respectively). Most surface-water samples had detectable levels of triazines, whereas fewer than half of the water samples from water-table wells and none of the water samples from deeper wells had detectable levels of triazine.

Selected water-quality constituents varied with time at the Vermillion River sites. The quality of water from deeper wells was much less variable with time than the quality of either surface water or water from water-table wells. For example, the average of the interquartile ranges for specific conductance of water from each of the deeper wells is only about 24 μS/cm (microsiemens per centimeter), in contrast to 220 μS/cm and 134 μS/cm for water from the water-table wells and the streams, respectively. The quality of stream water varied with time as flow varied. Specific conductance values of stream water were inversely related to flow. Nitrate concentrations in stream water, however, were not simply related to flow. Most surface-water samples with moderate levels of triazine (greater than 0.25 to 2 micrograms per liter) were collected during spring and during flows greater than the mean annual streamflow.

Selected water-quality constituents were related to selected physical factors. A waste-water treatment plant was a point source that accounted for most of the downstream nitrate loading in the Vermillion River mainstem. Water from sampling points with a large percentage (equal to or greater than 75 percent) of agricultural land in the contributing area had larger nitrate concentration (median 3.6 mg/L as nitrogen) than did water from sampling points with a smaller percentage of agricultural land (median below the detection limit of 0.1 mg/L as nitrogen). Water from areas with calcareous Quaternary or bedrock deposits could not be distinguished on the basis of calcium concentration from water from areas with noncalcareous deposits. Soil-leaching potential affected the relation between nitrate concentration in ground water and agricultural land. Nitrate concentrations were large (median 13.2 mg/L as nitrogen) where the percentage of agricultural land in the contributing area was large (equal to or greater than 75 percent) and where the soils had a large soil-leaching potential. Nitrate concentrations were small (median 3.2 mg/L as nitrogen) where the soils had a small soil-leaching potential, despite a large percentage of agricultural land. The statistical relation was not particularly strong, however: the null hypothesis that sites with different soil-leaching potentials had the same nitrate concentrations in ground water was rejected by the Kruskal-Wallis test at only the probability $P = 0.15$

level. Water-table depth was not an important factor in the relation between nitrate concentrations in ground water and agricultural land.

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