Similar Agricultural Areas, Different Ground-Water Quality: Red River of the North Basin, 1993-95

The U.S. Geological Survey has studied the ground-water quality within two areas of the Red River of the North Basin in southeastern North Dakota and west-central Minnesota. Although both areas are underlain by sandy surficial aquifers over which intensive irrigated agriculture dominates the land use, their ground-water quality differs. Ground water from the eastern study area has significantly higher concentrations of nitrate and agricultural herbicides than does ground water from the western area. Major differences in rainfall and minor differences in soils, depth to ground water, and agricultural practices between these two areas can account for the differences measured in ground-water quality. These same factors may indicate changes in ground-water quality from agricultural land uses in other surficial aquifers in the Red River of the North Basin.

Land Use and Ground-Water Quality

Wherever people use the land, their activities can change the natural concentrations of chemicals found in the ground water below. Most of the land through which the Red River of the North and its tributaries flow (the Red River Basin) is used to grow crops. Therefore, farming can affect the concentrations of chemicals in, or quality of, the ground water which flows at shallow depths beneath large areas of the basin. Many factors influence the degree to which farming changes the ground-water quality below it. These factors fall into three broad categories. **Weather factors** include how much rain and snow falls, when it falls, and how the temperature changes, both through the year and between years. **Soil factors** include the natural ground-water quality, the type of the soils through which the ground water moves, the depth to the ground water, and the bacteria which live in the ground. Finally, **agricultural factors** include which crops are grown, how the land is tilled and fertilized, how weeds and insects are controlled, whether or not the land is irrigated, and the source and quality of the irrigation water.

The sandy, surficial aquifers studied in this report provide abundant ground water for irrigation but provide little protection from chemicals used in agricultural production.

How do these factors influence the ground-water-quality changes that farming produces in the Red River Basin? This question is too complicated to answer completely. To begin to answer it, however, the U.S. Geological Survey (USGS) studied two areas of the Red River Basin which are susceptible to ground-water-quality changes from land use. Because both areas contained similar irrigated crops, they were also likely to have similar ground-water quality. To reduce the range of factors influencing farming effects on water quality, we chose areas with similar weather, soils, and agricultural practices. If the ground-water quality in these areas is not similar, then the normally small differences in weather, soils, and agriculture between them may be responsible. The two study areas are the Sheyenne Delta area of southeastern North Dakota and the Otter Tail area of west-central Minnesota. (See map to the left and the maps on the next page.)

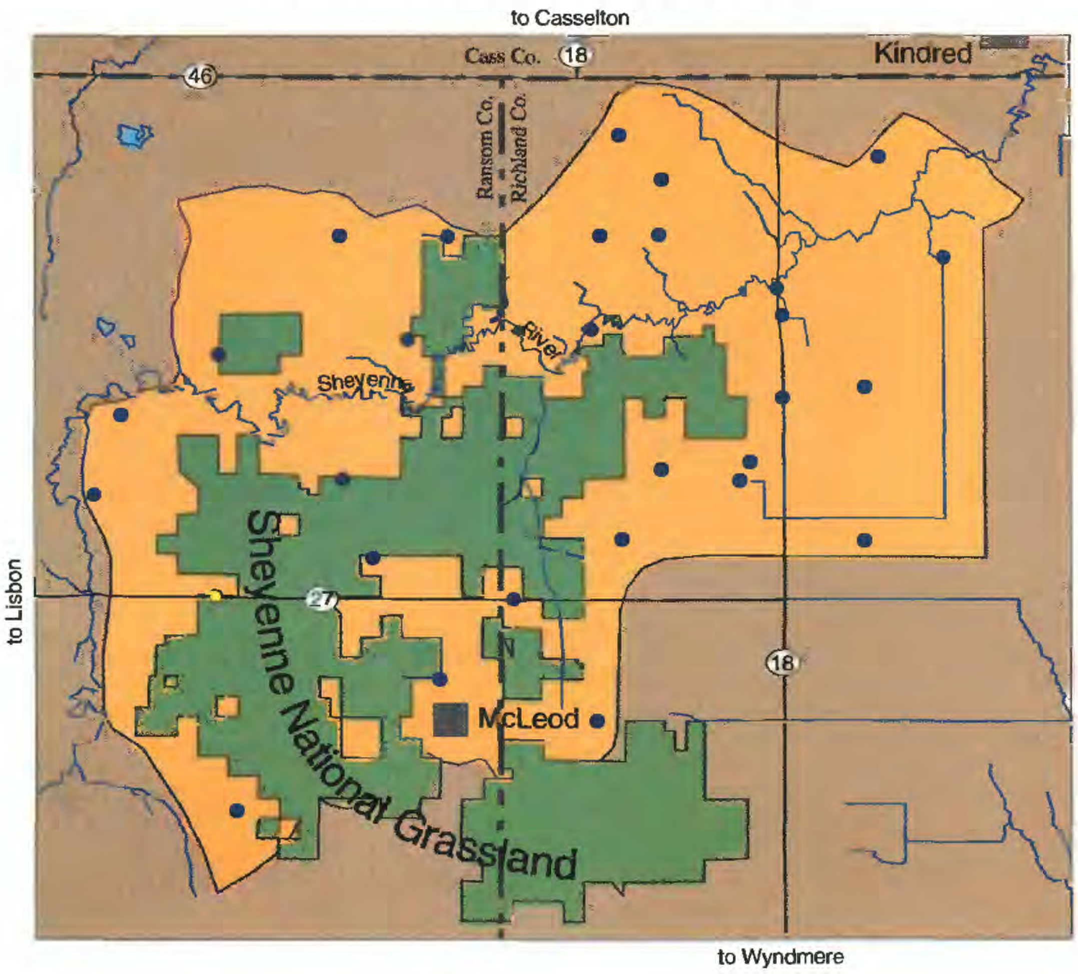
The Study Areas

The main crops grown in both study areas were corn, hay, beans, and small grains. Farmers also grew sunflowers in the Sheyenne Delta area. Growers apply fertilizers and pesticides to crops at about the same rate in both areas. Much of the crop acreage was irrigated with ground water. Irrigation water keeps soil near the surface more saturated than normal. If rain falls on a recently irrigated area, it can flush chemicals through the soil into the ground water. Thus, irrigated areas tend to magnify any ground-water-quality changes from farming.

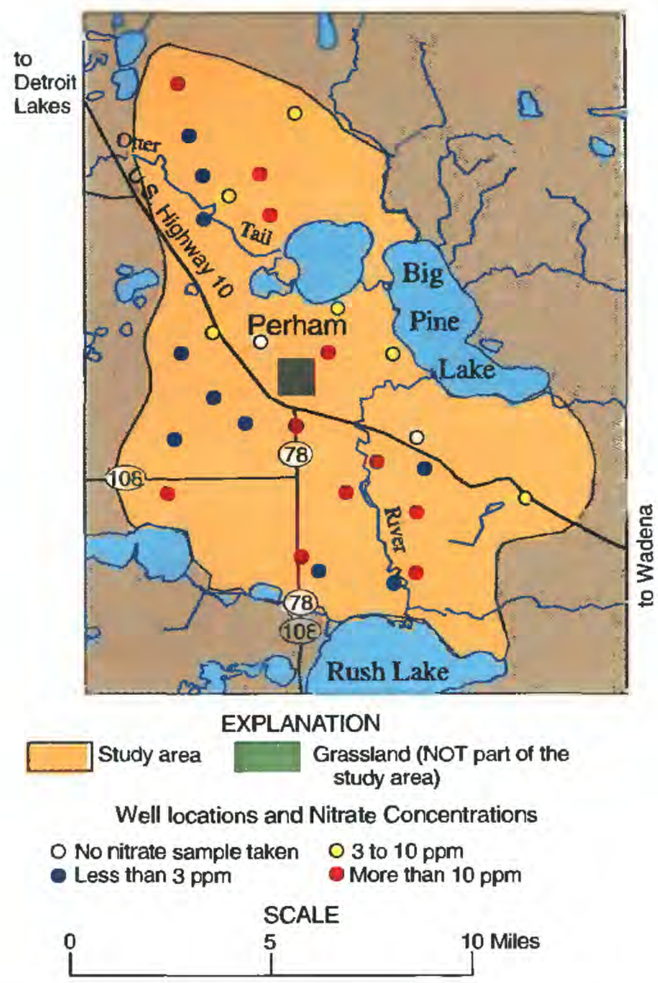
The study areas overlie the two largest of the sandy, surficial aquifers in the Red River Basin. These aquifers, which are water-bearing sands and gravels that have no large areas of clay layers above them, are common throughout the basin. Because water moves slowly through clay layers, they tend to shield underlying ground water from chemicals used above. The absence of overlying clay layers in surficial aquifers makes the ground water they contain particularly susceptible to quality changes from land uses.

We defined each study area as that part of the land above the aquifer that: 1) is used intensively for irrigated crop production, and 2) drains to the local river. These study areas are delineated in the maps

Sheyenne Delta Study Area



Otter Tail Study Area



above. Within each study area, a computer randomly chose 29 well sites. Water from one shallow, short-screened well at each site was sampled once for common ions (calcium, magnesium, etc.), nutrients, dissolved organic carbon, and pesticides. Because such wells did not usually exist at the selected sites, most of the wells sampled in this study were newly installed. These wells yield young water which is most likely to have been affected by recent farming. Young ground water is rain or irrigation water that has recently percolated to the water table to become ground water. (See ground water ages in the diagram on the top of the last page.) Samples of this young water can be considered an early warning of changes in ground-water quality from recent land uses. Wells in the Sheyenne Delta area were sampled during July and August 1993 and those in the Otter Tail area, during June and July 1994. Wells were installed and sampled with procedures designed to ensure that the water taken from the well is chemically the same as the water in the aquifer. All samples were analyzed by the USGS National Water-Quality Laboratory.

Nitrate and Pesticides in Shallow Ground Water

Results from these two study areas indicate that concentrations of nitrate and agricultural herbicides are higher in the shallow ground water from the Otter Tail area than from the Sheyenne Delta area.

Nitrogen is an important crop nutrient and is one of three elements in fertilizer. Fertilizers degrade to nitrate when not used by plants and easily dissolve into the water. Water with high concentrations of nitrate is a health threat if it is consumed by infants and animals. The maps of the study areas shown above present nitrate concentrations in three groups. Ground water with nitrate concentrations less than 3 parts per million (ppm; technically, NO_3 as N in mg/L) is shown as a blue dot. A previous study by Madison and Brunett (1984) has shown that concentrations in this range are likely to be natural. Ground water with nitrate concentrations from 3 to 10 ppm is shown as a yellow dot. This water is somewhat affected by additions of nitrogen to the environment from human activities. Ground water with nitrate concentrations greater than 10 ppm is shown as a red dot. This water is substantially affected by nitrogen from human activities and is higher than the drinking water standard established by the U.S. Environmental Protection Agency (USEPA).

These results demonstrate that 63 percent (%) of shallow ground water from the Otter Tail area showed some influence of nitrogen from human activities. Only 3% of water from the Sheyenne Delta area showed such influence. Further, 41% of the shallow ground water from the Otter Tail area exceeded the nitrate drinking water standard. The range of nitrate concentrations for both areas is presented in the yellow bar on the right side of the figure on the facing page. In the two worst cases, both in the Otter Tail area, the nitrate concentrations were four times higher than the drinking water standard.

Pesticide concentrations show a similar but less extreme pattern in the two study areas. These data are presented in the green boxes of the figure on the facing page. Samples from all sites were tested for 80 nationally-used pesticides (see Tornes & Brigham, 1995 for a complete list). Many, but not all of these pesticides were used in the study areas. A total of 10 pesticides and 2 metabolites (the product of a pesticide as it begins to break down) was detected in both study areas together. All of these pesticides are herbicides (weed killers) and most are used in corn production. Ground water from the Otter Tail area contained more kinds of herbicides, at generally higher concentrations, than did ground water from the Sheyenne Delta area. This trend is most apparent with atrazine and its metabolite, desethylatrazine. Concentrations of all pesticides were quite low; less than one part per billion (ppb) except for one sample from the Otter Tail area with a high atrazine concentration and one from the Sheyenne Delta area with a high picloram concentration. Although the highest concentration of any herbicide was 2.4 ppb of atrazine, this concentration is still below the USEPA drinking water standard of 3 ppb. Standards have been established for three other detected herbicides, but sample concentrations were 10 to

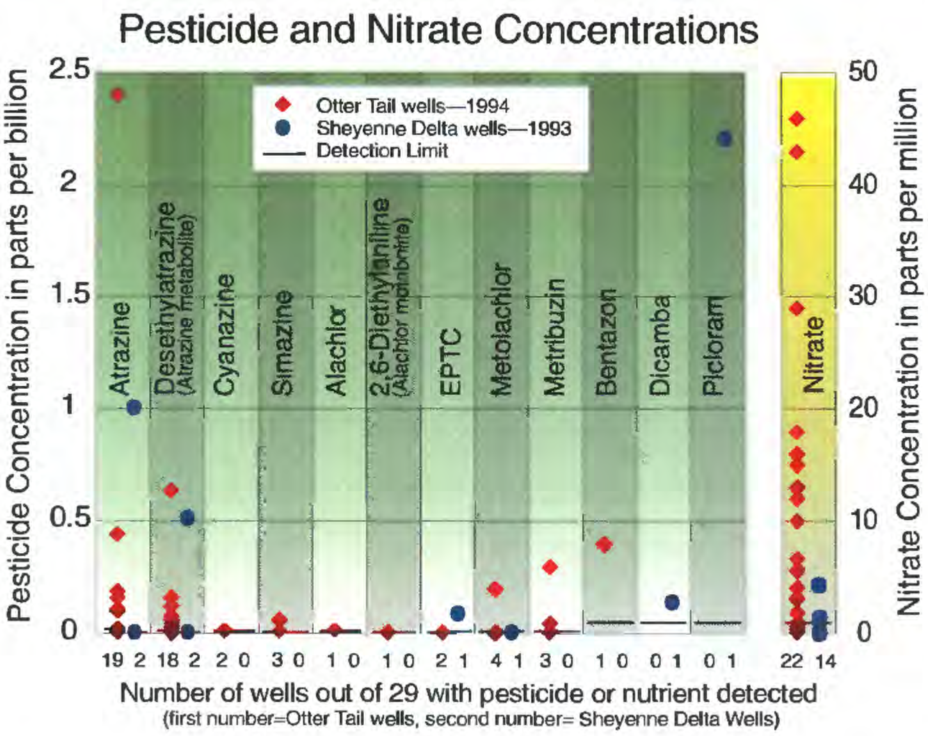
100 times lower than these standards. Because all of the tested herbicides are man-made, however, all of these herbicide detections are evidence of farming effects on ground-water quality.

Why Do These Waters Differ?

These nitrate and herbicide results show that the shallow ground water has been changed by farming much more in the Otter Tail area than in the Sheyenne Delta area. This is a surprising conclusion since the two areas were quite similar, given the large range of weather, soils, and agriculture throughout the Red River Basin. What characteristics of these areas can account for the differences in shallow ground-water quality we have observed?

Weather

Although both study areas usually have similar weather, a large difference in rainfall and temperature occurred between 1993 and 1994. During the 1993 sampling period, the Sheyenne Delta area experienced unusually high rainfall (166% of the 31 year average) and cool temperatures. This weather allowed much of the rain to soak into the sandy soils. When rain falls on a field which has been fertilized or treated with pesticides, some of these chemicals dissolve into the water and are carried to the ground water. If the water stays in the upper part of the soil long enough, however, plants can use the nitrogen, while some bacteria, living on the organic matter in the soil, can actually eat nitrates and pesticides. The depth from land surface to ground-water in the Sheyenne Delta area was generally quite shallow (average about 6.4 feet) during the 1993 sampling period. In many places the ground was completely saturated, causing large, shallow ponds to form in fields. This ponded water prevented both planting and application of fertilizer and pesticides in some areas. Further, percolating water from the high



rainfall could have diluted nitrate and pesticide concentrations already in the ground water as it moved to the water table. Finally, once the rain reached the shallow water table and became ground water, it was still in the soil zone where bacteria could continue to degrade these chemicals.

During the 1994 sampling period, rainfall in the Otter Tail area was more usual, even a little drier than normal (80% of the 31 year average). Ground water here was over twice as deep (average about 13.9 feet) during the 1994 sampling period than it was in the Sheyenne Delta area in 1993. The deeper ground water levels in the Otter Tail area allowed nitrate and herbicides in the percolating water to move beyond the soil bacteria, preventing further degradation. The unusually wet weather during the 1993 sampling period helps to explain why ground water from the Sheyenne Delta area had lower concentrations of nitrate and herbicides than did ground water from the Otter Tail area. However, this trend is true even during years of normal weather when the Sheyenne Delta area receives less rain than does the Otter Tail area. Some soil and agricultural differences between the two areas must also explain the ground-water-quality differences noted above.

Soils and Agriculture

Small, but important, differences in soils and agricultural practices do exist in these similar study areas. Generally, the Otter Tail area soils are coarser and more uniform in size than are the Sheyenne Delta soils. These soil characteristics permit rain to percolate faster in the Otter Tail area, allowing chemical-laden rain water to move past the soil quickly, into the aquifer beneath. Percolating water in the Sheyenne Delta area moves more slowly, allowing bacteria in the soil to more thoroughly degrade chemicals before they reach the ground water.

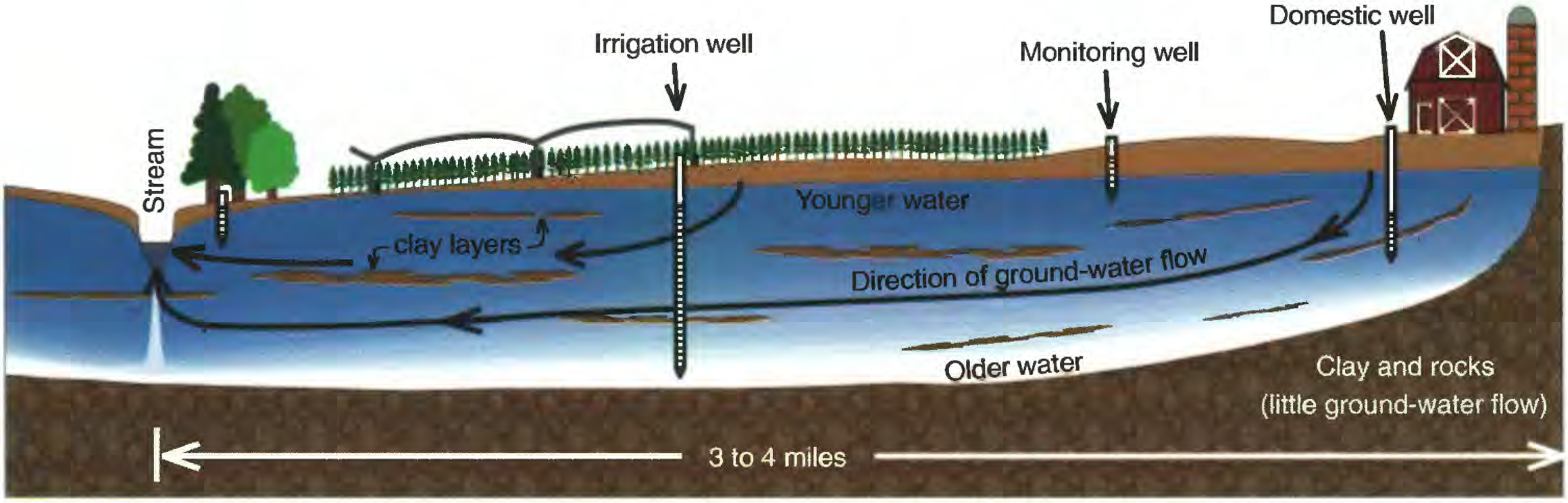
Although irrigated agriculture is common in both areas, the Sheyenne Delta area surrounds a large, unirrigated grassland area used for grazing. Ground water generally flows from this grassland into the study area. The effects of this land use on ground-water quality cannot be easily separated from those of the farming within the Sheyenne Delta area. Because fertilizer and pesticide use are very small in the grassland, the relatively unaffected ground water flowing from the grassland dilutes nitrate and pesticide concentrations in the study area. Within the Otter Tail area, land not used for crops is rare and evenly scattered. Therefore, crop chemicals will affect the ground water more in the Otter Tail area than in the Sheyenne Delta area.

Irrigation also influences the ground-water-quality differences between these two areas. Although irrigation with ground water is common in both areas, it is less common on the Sheyenne Delta and is not evenly distributed across the area. When rain falls after irrigation water has moistened soils, both waters are more likely to percolate downward, carrying dissolved agricultural chemicals with them into the ground water. Therefore, the more prevalent irrigation found in the Otter Tail area can contribute to the higher concentrations of nitrate and herbicides found there.

Implications for Ground-Water Quality

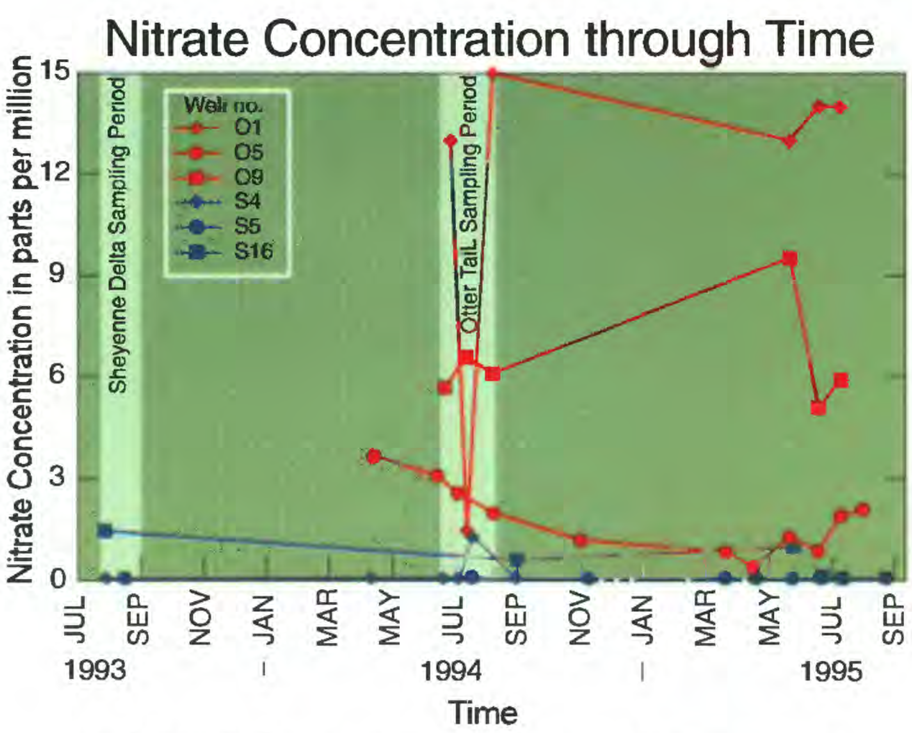
These weather, soil, and agricultural differences between the two similar study areas collectively can explain why concentrations of nitrates and herbicides were higher in shallow ground water in the Otter Tail area in 1994 than in the Sheyenne Delta area in 1993. This study shows that small differences between these two areas can have large effects on the concentration of nitrates and herbicides in the shallow ground water. Farming practices in the Sheyenne Delta area seem to have had only a small effect on ground-water quality while similar practices in the Otter Tail area introduced herbicides into the shallow ground water and raised nitrate concentrations above the drinking water standard. Key factors like lower rainfall, warmer temperatures, coarser and more well sorted soils, deeper ground water, smaller areas of non-crop land, and more irrigation produced larger farming effects on shallow ground-water quality. Sandy surficial aquifers underlying areas of irrigated crop production are common along the margins of the Red River Valley and its upland areas. Areas of the Red River Basin similar to the study areas, but which have weather, soils, and agricultural conditions more in common with the Otter Tail area, can expect to have shallow ground water that is more affected by the farming above it.

The samples used in this study were collected during a short span of time (about a month for each area). Do these water-quality results



Ground water in aquifers begins as rainfall, snow melt, or irrigation water at the ground surface. As more water percolates on top, the ground water is driven deeper into the aquifer and toward rivers and lakes. Therefore the older water is at the bottom of the aquifer and the younger is at the top. Ground waters of many ages converge at the rivers and lakes. Our monitoring wells obtain ground water just at the water table which is affected by the most recent land uses. Domestic and irrigation wells generally draw water from throughout the aquifer, mixing younger water with older water.

change over a longer time? The graph below shows the nitrate concentration in water from 3 wells from each study area through a period of 16 months to 2 years. There is no clear trend in the data. The nitrate concentrations in water from some wells from each study area increase, some decrease, and some remain near zero. Had we sampled both areas in July 1994, water-quality differences between the two areas could have been smaller, even though concentrations in the Otter Tail area would still have been higher. Sampling both areas in July 1995 could have increased the water-quality differences between the areas.



Red=Otter Tail area wells, Blue=Sheyenne Delta area wells

These changing concentrations demonstrate how difficult it is to identify and separate the various weather, soil, and agricultural factors responsible for the ground-water quality in a certain place at a certain time. The shallow ground water in some areas of these sandy aquifers is certainly sensitive to weather and farming changes, however. The shallow ground water sampled in this study is the youngest and most vulnerable water in the aquifers. Although it is rarely used for drinking, this shallow water will with time become deeper ground water as more rain percolates down on top of it. In the absence of chemical degradation, the quality of shallow ground water can eventually influence water quality deeper in an aquifer. In this sense, the information in this report is an early warning about farming effects on ground-water quality throughout surficial aquifers.

This study is part of the USGS National Water-Quality Assessment Program. The purpose of the program is to assess the quality of a large, representative part of the Nation's water. In addition to ground water, the USGS is also studying the quality of surface water and the health of aquatic plants and animals. The first major phase of the program in the Red River of the North Basin began in 1991 and ends in 1995.

Suggestions for Further Reading

Cowdery, T.K. and Goff, K., 1994, Nitrogen Concentrations near the Water Table of the Sheyenne Delta Aquifer beneath Cropland Areas, Ransom and Richland Counties, North Dakota, *in* North Dakota Water Quality Symposium Proceedings, March 30-31, 1994, Fargo, North Dakota: North Dakota State University Extension Service, pp. 89-102.

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

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U.S. Geological Survey Open File Report 95-441
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