

**GROUND WATER MONITORING IN THE VERDI WELLHEAD PROTECTION
AREA – 2000 ANNUAL REPORT**

Minnesota Pollution Control Agency

Prepared by the Ground Water Monitoring and Assessment Program

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Abbreviations

BMPs	Best Management Practices
CRP	Conservation Reserve Program
LCMR	Legislative Commission on Minnesota Resources
LPRWS	Lincoln-Pipestone Rural Water Supply District
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MPCA	Minnesota Pollution Control Agency
UM	University of Minnesota
WPA	Wellhead Protection Area

Abstract

The Verdi well field, in Lincoln County, Minnesota, supplies drinking water to a large area in Southwestern Minnesota. The aquifer in which the well field is completed has a history of elevated nitrate concentrations. Unfortunately, there is insufficient information to determine time trends in concentration, making it impossible to evaluate potential health risks to people consuming water from the aquifer.

In 1999 and 2000, the Minnesota Pollution Control Agency established a ground water monitoring network in the Verdi Wellhead Protection Area. The primary objective of the study is to evaluate long-term impacts of agricultural management practices on ground water quality. The monitoring network includes ten monitoring wells, five public supply wells, and five surface water sampling locations. Sampling included discharge measurements in Spring Creek, water level measurements in monitoring wells, measurement of stable isotope concentrations in monitoring wells, and sampling for nitrate, chloride, pesticides, and other inorganic chemicals.

The Southwest Research and Outreach Center, University of Minnesota, Agricultural Research Service, Natural Resource Conservation Service, and the Soil and Water Conservation District offices have launched an aggressive education program to modify farmer behavior related to nutrient management. The Minnesota Department of Agriculture has coordinated the project through a grant provided by the Legislative Commission on Minnesota Resources.

This report summarizes monitoring efforts for 2000. We include recommendations for long-term monitoring in an Appendix. Long-term monitoring is critical for establishing baseline water quality conditions and evaluating the effectiveness of voluntary nutrient management programs.

Discharge measurements during 2000 indicate about 8 million cubic feet (60 million gallons) of water seeped through Spring Creek and presumably into underlying aquifers. Seepage primarily occurred during May and June. Seepage appeared to contribute to aquifer recharge, as indicated by changes in chloride and organic carbon concentrations in the aquifer in response to stream discharge. Results for stable isotopes indicate that recharge to the aquifer may be rapid since there was no evidence of

fractionation of ground water and there were distinctly different temperature signatures in ground water for the spring and summer sampling events.

Nitrate concentrations in the aquifer increased from north to south. Nitrate concentrations were correlated with Eh and chloride in monitoring wells but not in public supply wells. Two wells contained detectable concentrations of pesticides. The source of pesticide may be surface water seepage, since pesticides were detected in samples from Spring Creek.

Based upon results from sampling in 2000, we recommend the following activities:

- consolidate the monitoring network;
- continue sampling monitoring wells;
- continue monitoring stream discharge; and
- identify mechanisms of recharge.

We recommend quarterly sampling for nitrate, chloride, dissolved oxygen, Eh, and dissolved iron.

Introduction

The Lincoln Pipestone Rural Water Supply District (LPRWSD) operates three main well fields that serve 24 communities and 3000 farms in southwestern Minnesota. One of these well fields, the Verdi well field, consists of five public water supply wells. The Verdi well field occurs in an alluvial sand and gravel aquifer (Verdi aquifer) that appears to be semi-confined. Four of the five wells have nitrate-nitrogen¹ concentrations higher than 4 mg/l, with one well having a concentration exceeding the drinking water standard of 10 mg/l.

In September of 1997, the Minnesota Department of Agriculture (MDA) and Minnesota Department of Health (MDH) formed a steering committee to address water quality problems in Southwest Minnesota, including the Verdi well field. The steering committee assembled a technical committee to determine sources of nitrate to the Verdi aquifer and determine possible solutions and preventive actions. The technical group compiled information about the hydrogeology and land use of the Verdi area (December 9, 1997 report titled *Technical Committee Report to the Interagency Steering Committee Regarding Management of Nitrate Nitrogen Sources for the Holland and Verdi Well Fields*), including

1. livestock numbers and associated pounds of manure produced;
2. location of areas where manure was land applied;
3. location of feedlots;
4. acreage in different crops;
5. patterns of nitrogen application;
6. geology of the Verdi aquifer and overlying unsaturated zone; and
7. aquifer hydraulic properties.

Funding was obtained from the Legislative Commission on Minnesota Resources (LCMR) in 1998. Since then, the MDA and University of Minnesota (UM) have worked with local farmers operating in the wellhead protection area to develop and implement improved agricultural systems. The goals of these efforts are to provide technical assistance and education to farmers, provide cost-share for the implementation of nutrient management plans, and conduct research to refine existing Best Management Practices

¹ Throughout the document, nitrate refers to nitrate-nitrogen and ammonia refers to ammonia-nitrogen.

(BMPs) for nitrogen fertilizer management. The Verdi area therefore represents an unique opportunity to evaluate the effectiveness of BMPs in improving ground water quality.

Monitoring the effectiveness of BMPs requires long-term ground water monitoring. The MDA funding, however, was insufficient to establish a ground water monitoring network. In late summer, 1999, the MDA approached the Minnesota Pollution Control Agency (MPCA) to determine if a ground water monitoring network could be established in the Verdi Wellhead Protection Area (WPA). MPCA agreed to install a monitoring network to evaluate the effectiveness of BMPs in maintaining or improving ground water quality. MPCA established the monitoring network during the first half of 2000. The objectives of monitoring are to

- describe current water quality of the Verdi aquifer and establish a baseline water quality data set;
- identify factors affecting the distribution of nitrate in the aquifer; and
- monitor the effectiveness of nitrogen BMPs on maintaining or reducing nitrate concentrations.

Current LCMR research sites provide information on BMP effectiveness in individual agricultural fields, while the MPCA monitoring network provides information on general aquifer conditions.

Description of Study Area

Figure 1 illustrates the location of the study area. Figure 2 illustrates the location of the five public water supply wells and the WPA. The study area coincides with the WPA and includes the Minnesota portion of the Spring Creek Watershed (Figures 1 and 2).

The mapped extent of the aquifer (Figure 3) does not coincide with the WPA. The aquifer is mapped near the well field, which occurs near the western edge of the study area. This is an area where drilling logs are readily available and coarse-textured geologic materials are within about 30 feet of the land surface. Ground water model results (Figure 3) indicate the 10-year time of travel extends about 2.5 miles northeast of

the well field. The extent and location of the aquifer is uncertain beyond the 10-year time of travel (see section on Physical Information).

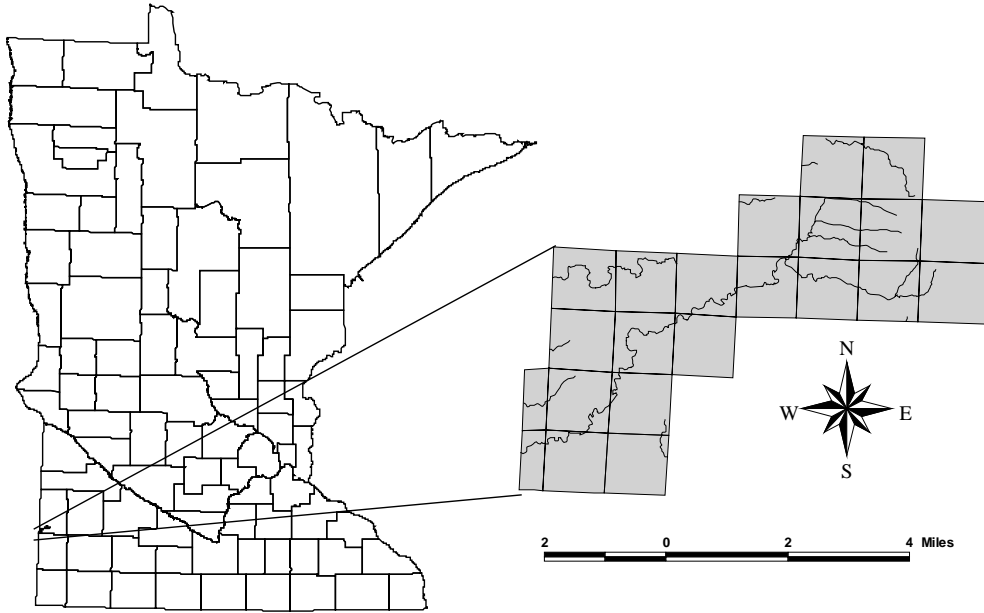


Figure 1: Location of study area. The shaded area illustrates the wellhead protection area, which includes the entire Minnesota portion of the Spring Creek Watershed.

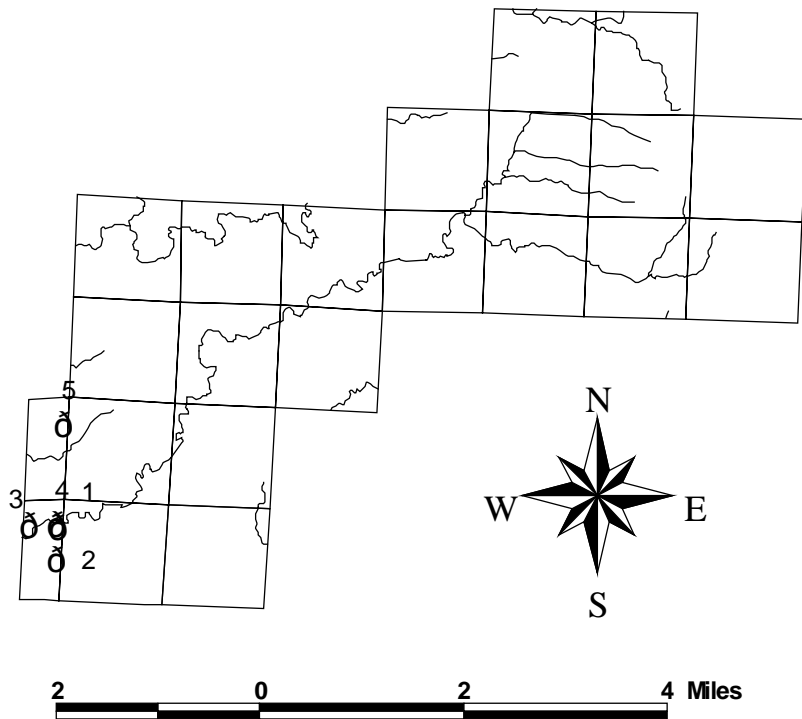


Figure 2: Location of public supply wells.

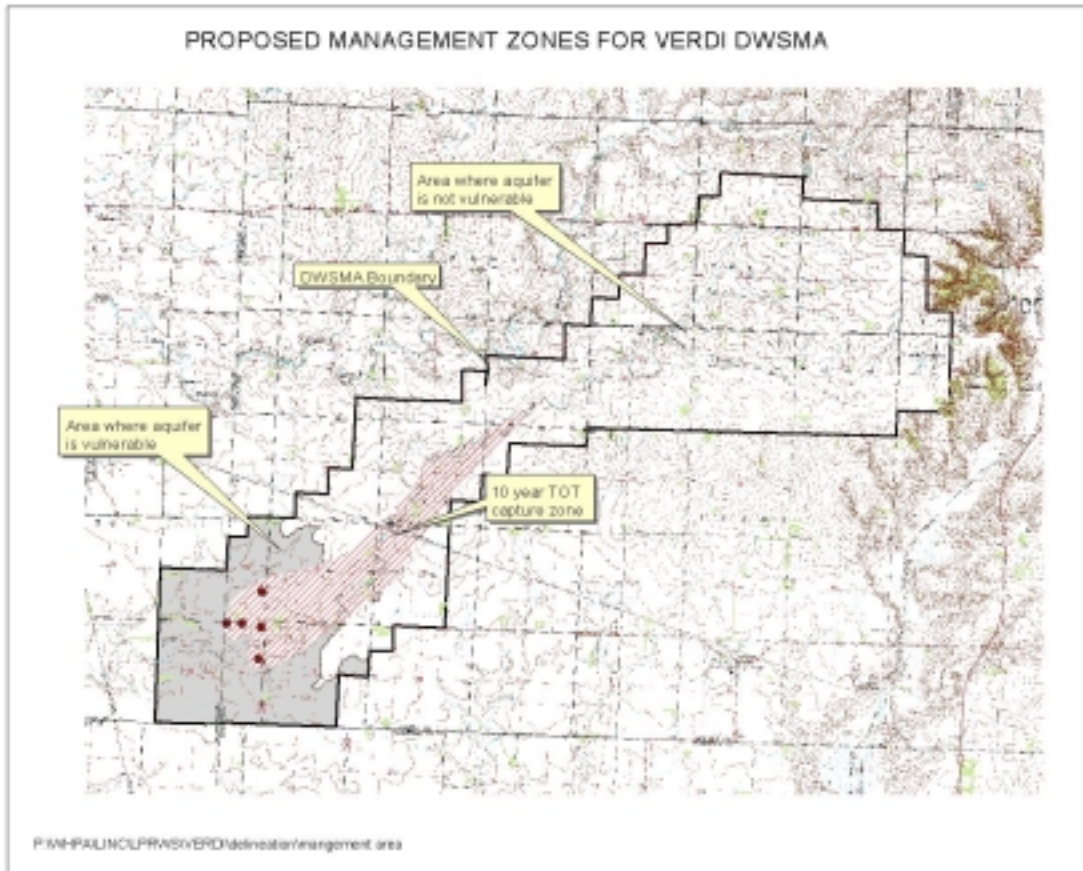


Figure 3: 10-year travel time (TOT capture zone) for the Verdi well field. The shaded area illustrates where the aquifer is considered vulnerable to contamination because coarse-textured geologic materials are at or near the land surface. The dots represent locations of the public supply wells.

The WPA extends beyond the 10-year time of travel zone because of uncertainty regarding the contribution of Spring Creek to ground water recharge. Spring Creek discharges to the southwest. Ground water flow is east to west and generally follows Spring Creek (see Figures 5 and 6). Spring Creek is a losing stream, but the quantity and fate of seepage water are unknown. If the quantity of seepage is large, then water quality in Spring Creek may impact water quality of the aquifer. Water quality of Spring Creek is likely to be affected by agricultural activities throughout the study area. Thus, the WPA includes Spring Creek Watershed.

Physical Information

The Verdi aquifer consists of saturated sand and gravel deposited by meltwater that issued from the Des Moines Lobe ice front (Patterson, 1995). In some areas, glacial deposits have been covered by alluvial deposits from Spring Creek. Dense clay loam till and loess deposits cover most of the aquifer, except near the public supply well field. The till varies in thickness from a few feet near the well field to more than 50 feet near the outer boundaries of the aquifer (Figure 4). Near the well field, till units are coarse-textured and discontinuous and do not appear to protect the underlying aquifer from contamination by mobile chemicals such as nitrate. The aquifer probably extends eastward from the well field as a series of narrow sand and gravel units buried below extensive deposits of till. These units are not mapped. Figures 5 and 6 illustrate cross-sections for the study area. The cross-sections illustrate the discontinuous nature of sand deposits and the presence of unsaturated sand layers.

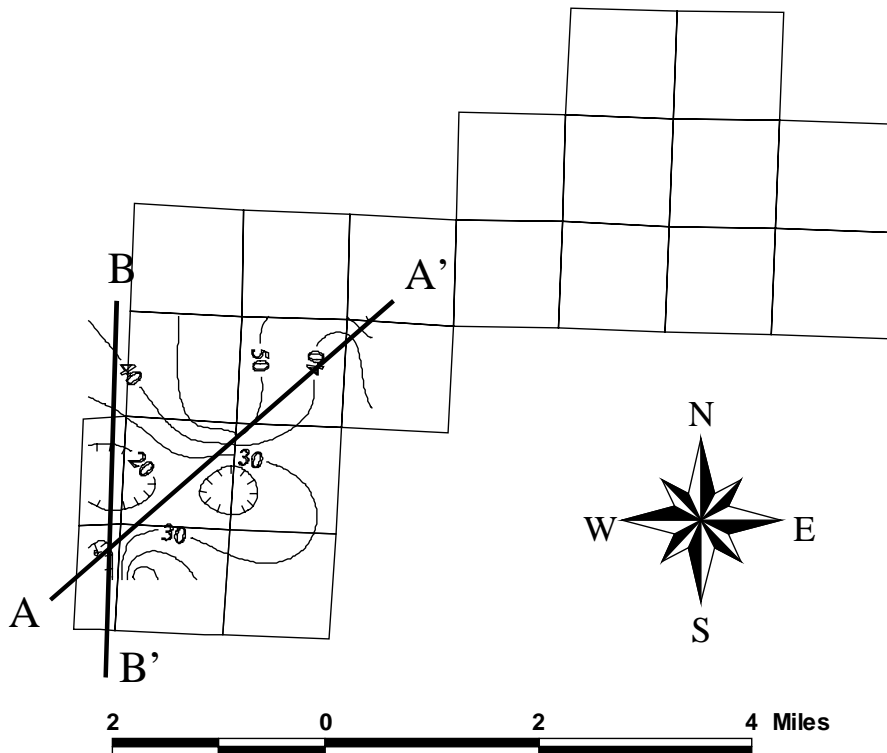


Figure 4: Contours of till thickness (feet) overlying the Verdi aquifer. The contour interval is 10 feet. Lines A-A' and B-B' correspond to transects for the cross-sections in Figures 5 and 6.

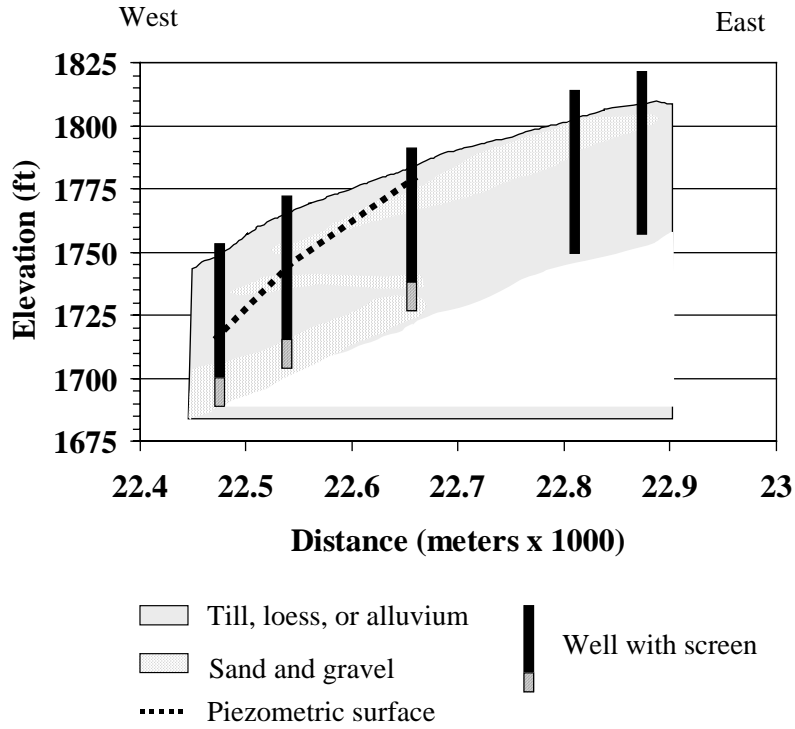


Figure 5: East-west (line A-A' in Fig. 4) cross-section through the aquifer. NOTE: Units for the x-axis are in meters, since location information in our database is in meters.

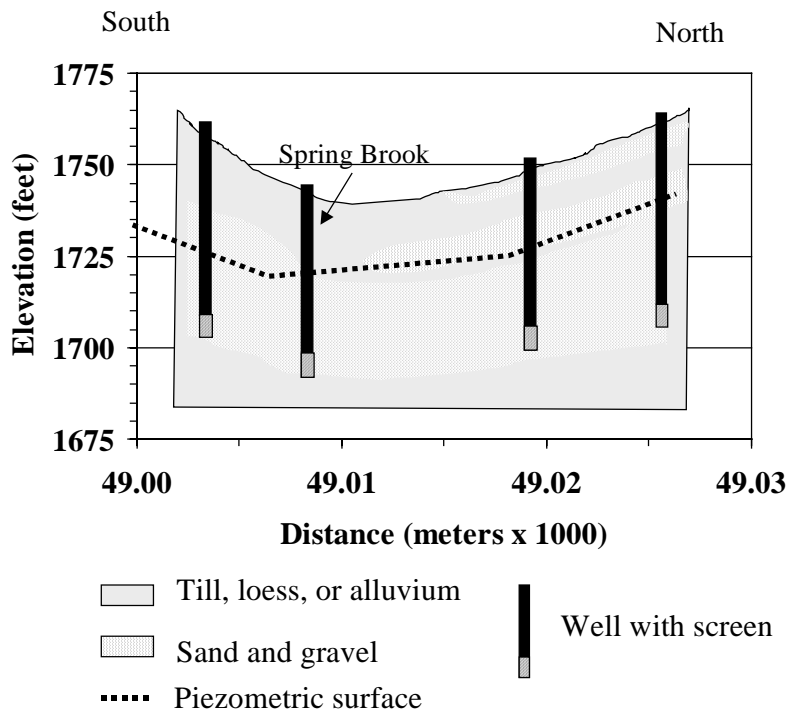


Figure 6: North-south cross-section (line B-B' in Fig. 4) through the aquifer. NOTE: Units for the x-axis are in meters, since location information in our database is in meters.

Three Soil Associations comprise soils in the study area (Figure 7). Soils of the Brandt-Estelline-Fordville association occur in the western third of the study area and consist of very deep, well drained soils formed in silty materials (primarily loess) overlying sand and gravel on outwash plains. Slopes are generally less than 2 percent. Outwash materials have very rapid permeability. Soils of the Kranzburg-Vienna-Hidewood association cover the central and eastern portion of the study area and consist of very deep, well-drained soils formed in silty glacial drift (till) or loess on uplands. Slopes are generally less than 2 percent. Soils of the Barnes-Langhei-Hamerly association occur in the extreme eastern part of the study area and consist of very deep, well drained, moderately, and moderately slowly permeable soils that formed in loamy till, on till plains, and on moraines. Slopes range from 0 to more than 20 percent (soil descriptions are provided through the United States Department of Agriculture, Natural Resources Conservation Service web site : <http://www.statlab.iastate.edu/cgi-bin/osd/osdnamequery.cgi>).

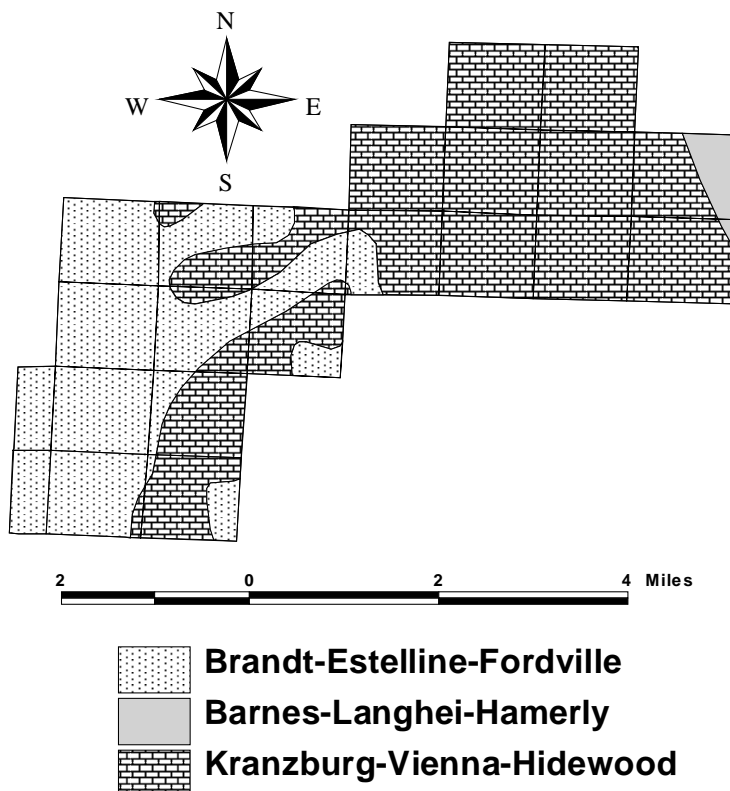


Figure 7: Distribution of soil associations within the study area.

Average annual precipitation is about 24.5 inches (Anderson et al., 1976). Average annual runoff is about 2.5 inches. There is insufficient information to determine the quantity and pattern (e.g. sources, timing) of recharge to the aquifer. Anderson et al. (1976) report a baseflow of about 3.74 ft³/s for Spring Creek near the well field. Concerns that the creek may be contributing to ground water recharge prompted inclusion of the entire Spring Creek Watershed into the WPA.

Water Quality Information

There is limited information on nitrate concentrations in individual public water supply wells (Figure 8)(nitrate data were supplied by the LPRWSD). Water quality samples were collected from individual wells between 1987 and 1991, and since 1997. Samples of blended water have been collected since the early 1990's. Sampling has been erratic, with only one sample collected in most years during the early 1990's, while five or more samples were collected each year between 1997 and 1999. Figure 9 illustrates precipitation and nitrate concentrations of blended water (precipitation data were obtained from the Department of Natural Resources, Minnesota Extension Service, and UM Climatology Working Group web site: <http://climate.umn.edu/>, for the National Weather Service location at Pipestone, Minnesota). There was no correlation between precipitation and nitrate concentration, either in individual public supply wells or for blended water. Table 1 summarizes median nitrate concentrations in individual wells and for blended water. Nitrate concentrations exceed the drinking water standard of 10 mg/l in Well 2, while Well 5 has non-detectable concentrations. Iron and manganese concentrations are highest in Well 5 (Table 2), indicating the presence of nitrate-reducing conditions.

Nitrate concentrations in blended drinking water were not significantly correlated with specific conductance, pH, and concentrations of calcium, magnesium, sodium, potassium, sulfate, chloride, bicarbonate, iron, and manganese. There was no significant trend in nitrate concentration in blended water ($p = 0.127$), using data collected since 1987. There was insufficient information to conduct trend analysis for individual wells.

Concentrations of other water quality constituents are generally low and within acceptable ranges for drinking water (Table 2). Ground water in the aquifer is calcium-

bicarbonate type (Hounslow, 1995), although concentrations of sulfate are much higher than the statewide median concentration of 5.8 mg/l for similar types of aquifers (MPCA, 1998a).

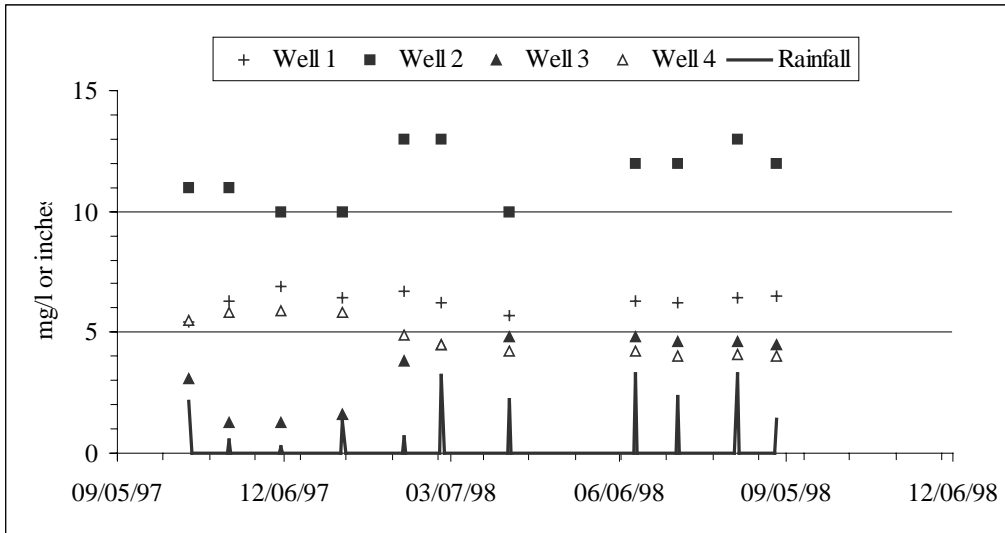


Figure 8: Distribution of nitrate in supply wells 1, 2, 3, and 4. Data for Well 5 are not shown because there were only three sample events.

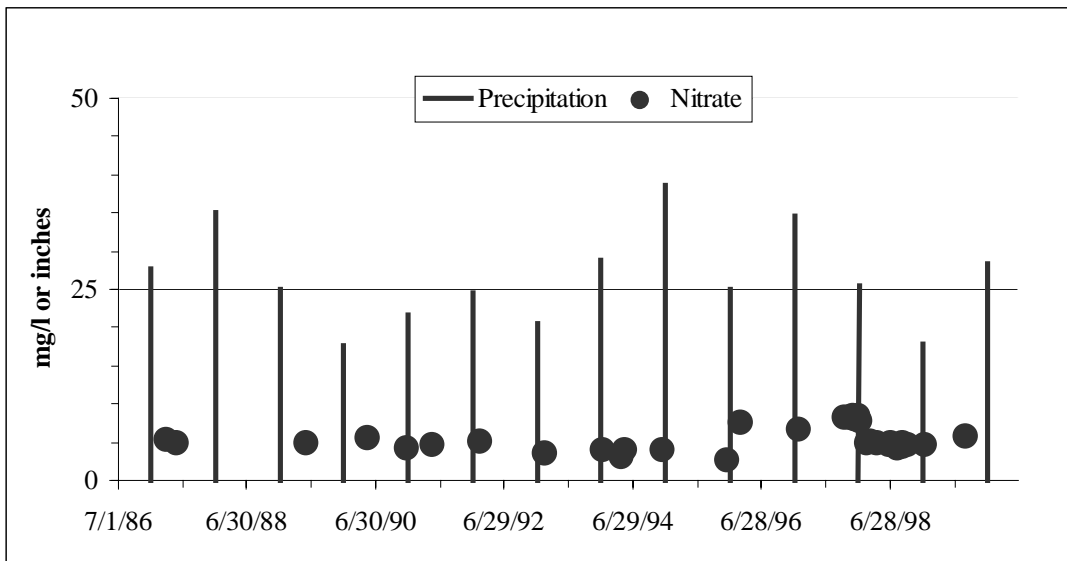


Figure 9: Annual precipitation and distribution of nitrate in blended drinking water. Annual precipitation represents the sum of all precipitation events for the preceding twelve months.

Well number	Initial Sampling Date	No. samples	Nitrate (mg/l)
1	1987	14	6.00
2	1987	13	11.00
3	1989	12	5.00
4	1989	12	4.00
5	1989	3	< 0.10
Blended water	1987	33	4.90

Table 1: Median nitrate concentrations in Wells 1 through 5 and in blended drinking water.

Chemical	Well 1	Well 2	Well 3	Well 4	Well 5	Drinking criteria ¹
Calcium (mg/l)	102	83	86	95	91	-
Magnesium (mg/l)	32	31	31	34	27	-
Sodium (mg/l)	6.0	6.5	7.0	8.0	12.0	-
Potassium (mg/l)	3.0	2.0	2.0	2.0	3.0	-
Sulfate (mg/l)	65	29	61	84	85	250
Chloride (mg/l)	14.0	5.0	5.0	4.0	3.5	250
Alkalinity (mg/l)	288	264	284	292	252	-
Iron (mg/l)	nd	nd	nd	nd	0.4	0.3
Manganese (mg/l)	nd	nd	nd	nd	0.3	0.1
Specific conductance (umhos/cm)	700	650	650	750	800	-
PH	7.42	7.29	7.43	7.27	7.23	-

¹ Drinking criteria are the Secondary Maximum Contaminant Level for sulfate, chloride, and iron, and the Health Risk Limit for manganese. The remaining chemicals have no criteria.

² nd = not detected

Table 2: Median chemical concentrations in public water supply wells. Data were collected between 1987 and 1991 and since 1997.

Location of Agricultural Management Areas

Figure 10 illustrates locations of agricultural management areas. These are areas where landowners and farmers are working with the MDA, UM, and local agencies to implement BMPs. Most of the acreage is cropped in corn-soybean rotations. There have been few changes in land use within the study area over the past ten years, with a slight increase in the amount of land set aside in the Conservation Reserve Program (CRP). All of the land in the well field is owned by the LPRWSD and has been converted to CRP. Digitized land use information does not exist for the study area. In preparing this report, we did not collect historical and present land use information across the study area. This

information could provide valuable insight for comparing changes in agricultural practices after implementation of the BMPs. The data are also useful for evaluating potential contributions from headwater areas of the Spring Creek Watershed. Historical and present land use information can be collected through historic aerial photos and through local surveys and interviews.

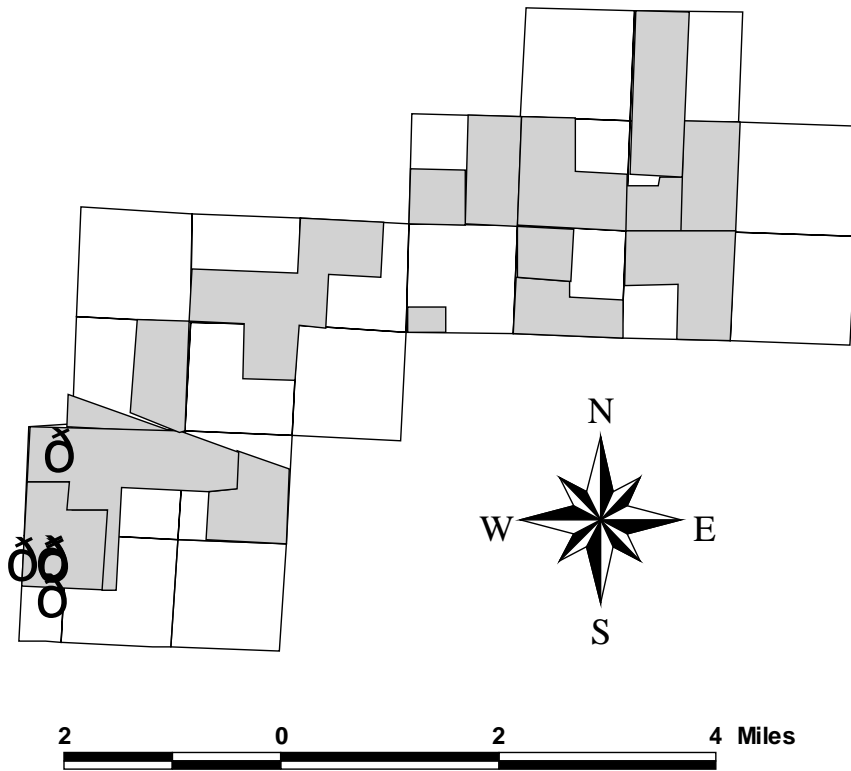


Figure 10: Location of agricultural management areas. Outlined, shaded areas represent individual farms where voluntary nutrient management practices are being implemented. Cross-hatched circles show locations of the public supply wells.

Materials and Methods

Establishment of the Monitoring Network

Between January and June 2000, MPCA staff established a ground water and surface water monitoring network in the study area. We installed six monitoring wells in February and four additional wells in June. Drilling methods are described in MPCA (1998b).

Figure 11 illustrates the location of monitoring wells and supply wells. On May 25, water level recorders were inserted into two of the monitoring wells. One water level

recorder was located near the well field and the other up-gradient of the well field. Measurements from these wells provide information on recharge to the aquifer. Recorders measure water levels at sixty-minute intervals. Since April, two to four continuous recording surface water (stream) gauges have recorded the elevation of water in Spring Creek. Measurements are recorded at fifteen-minute intervals. Stream discharge has been measured on two occasions. Stream discharge measurements are needed to establish a relationship between water elevation and discharge in the creek. Knowing this relationship, we can calculate flow (discharge) volumes based on water level measurements from the continuous recorders.

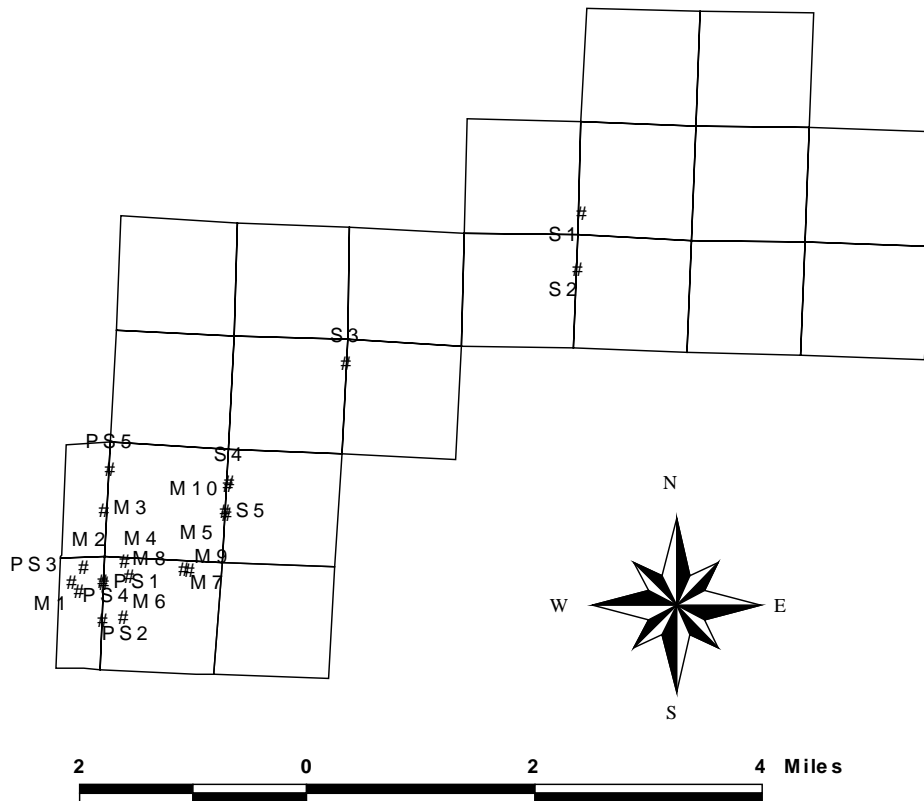


Figure 11: Location of monitoring wells, public supply wells, and surface water sampling points. S = surface water, M = monitoring well, PS = public supply well.

Data Collection

We sampled monitoring wells on March 1, April 18, May 31, and July 24, 2000. We collected samples from Spring Creek on May 25. A peristaltic pump was used to obtain water from the wells and from Spring Creek. Continuous measurements of

oxidation-reduction potential (mV), temperature ($^{\circ}\text{C}$), pH, specific conductance (umhos/cm), and dissolved oxygen (mg/l) were taken using a YSI 600 XL² multiparameter probe. Samples were collected once temperature, specific conductance, and pH had stabilized to 0.1 $^{\circ}\text{C}$, 10%, and 0.1 pH unit, respectively, for three successive readings. Samples for inorganic chemicals were analyzed at the UM Research Analytical Laboratory. Samples for isotopes of oxygen (^{18}O) and hydrogen (^2H) were collected during the April and May events and analyzed at the Environmental Isotope Lab in Waterloo, Canada. The distribution of these isotopes in ground water provides an indication of the source of recharge to the aquifer (Coplen, 1993). Agricultural herbicides were sampled in April and analyzed using GCMS at the United States Geological Survey Analytical Laboratory in Lawrence, Kansas. All samples for laboratory analysis were packed in coolers at 4 $^{\circ}\text{C}$ and delivered to laboratories within required holding times. Appendix I summarizes the chemical parameter list, laboratory analysis method, and laboratory reporting limits. We collected field duplicates at a rate of 10 percent.

Data Analysis

We used nonparametric methods (Kruskal-Wallis for group tests and Spearman Rank Method for correlation analysis) to compare concentrations in wells, to compare concentrations in ground and surface water, and to determine if nitrate concentrations were correlated with concentrations of other chemicals, precipitation, physical parameters such as sand thickness, and surface water characteristics. All data below a reporting limit were censored following procedures described in MPCA (1998a). As we collect additional information on land use and application of BMPs, we will conduct statistical analysis to determine if correlations exist between land use and water quality and to evaluate the effects of BMPs on water quality. After four years of sampling, we will conduct trend analysis using a nonparametric version of the seasoned Kendall-Mann test.

At this time, we are lacking information on historical land use, mechanisms of aquifer recharge, and quantity of recharge. It appears unlikely that trends in ground water quality will be observed within four years, even if BMPs continue to be practiced. It is

² Mention of a particular product does not represent preference for or endorsement of that product.

therefore important to continue monitoring for several years. Trend analysis will be performed following each year of data collection.

Results and Discussion

Recharge

Figure 12 illustrates stream discharge for upgradient and downgradient locations within the study area. The upgradient data reflect combined discharge at Sites S1 and S2. The downgradient site corresponds with Site S3. There was minimal streamflow after mid-July. We calculated a total loss of 8×10^6 cubic feet (60 million gallons) between the Sites S1 and S2 and Site S3. Total discharge during 2000 was 9 million cubic feet at Site S2, 7 million cubic feet at Site S1, and 8 million cubic feet at Site S3. This indicates a loss of about 50 percent of streamflow between the up- and downgradient locations. We have not identified the fate of this water. There is chemical evidence that some of this water mixes with aquifer water (see the next section on water quality).

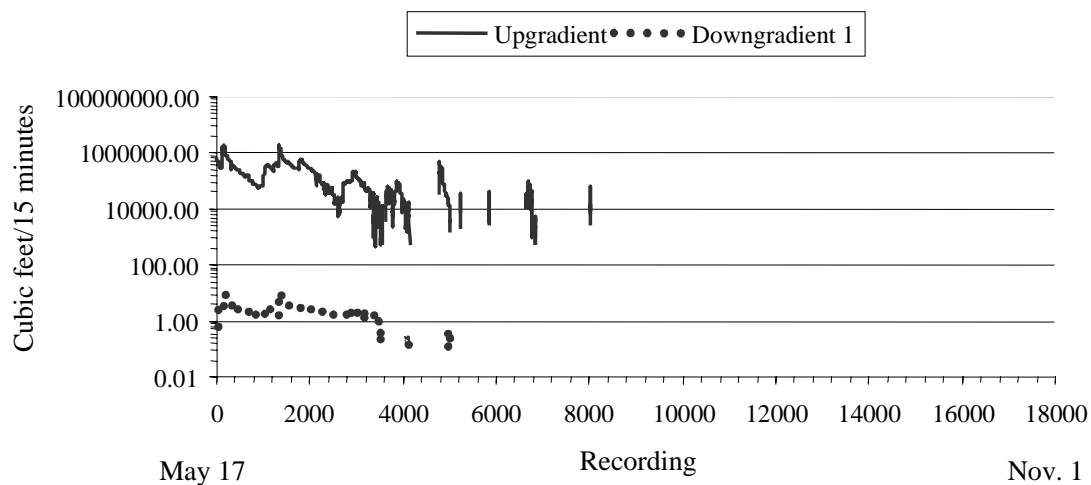


Figure 12: Discharge in spring Creek during 2000. Data for the upgradient location represents combined flow for Sites S1 and S2. The downgradient location is represented by Site S3. See Figure 11 for sampling locations.

Figure 13 illustrates precipitation and combined stream discharge at Sites S1 and S2. Stream discharge was greatest in May and early June. Discharge correlated strongly with precipitation during this period. After mid-June, stream discharge was zero except following significant precipitation events. Stream discharge occurred for one to three

days following the precipitation events of June 24, June 28, and July 6. The 0.49 inches of precipitation on July 10 and 0.69 inches on July 17 led to stream discharge for two to three hours. After August 1, stream discharge was zero except following the 0.92 inch rainfall on August 9. The 0.64 rainfall of October 17, which was well past the crop growing season, did not result in stream discharge. Evapotranspiration dries surface soils in the summer. Much of the precipitation goes into rewetting soils, which dramatically reduces runoff and streamflow. These conditions persisted into the autumn of 2000 due to low summer precipitation.

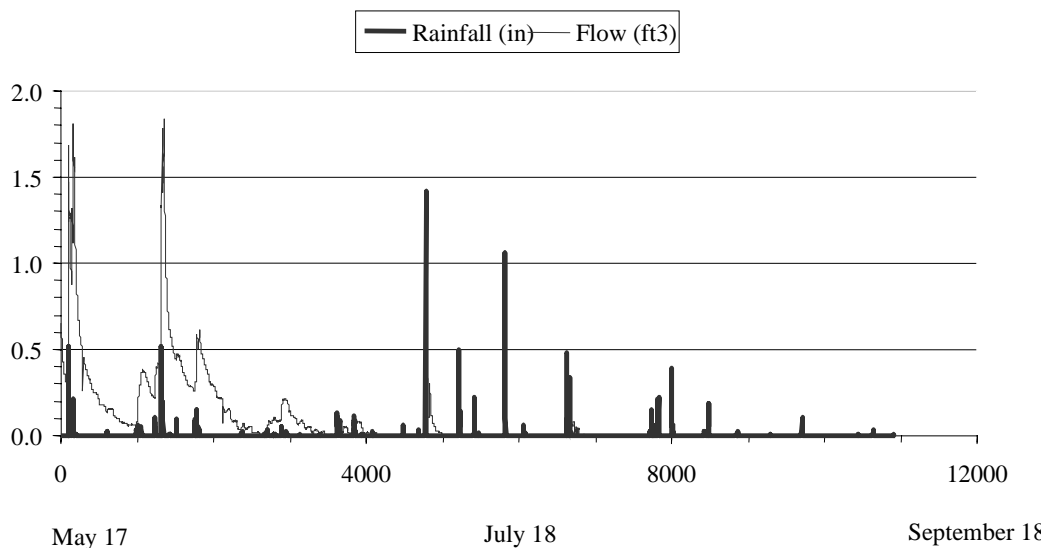


Figure 13: Precipitation and combined flow at upgradient Sites S1 and S2. Streamflow is in millions of cubic feet.

The distribution of stable isotopes of oxygen and hydrogen provide useful information for understanding aquifer recharge. Winter precipitation is depleted in ^2H and ^{18}O relative to summer precipitation. Furthermore, evaporation leads to enrichment of ^2H and ^{18}O in water, resulting in $^2\text{H}/^{18}\text{O}$ slopes of 3 to 6 compared to a slope of about 8 for precipitation water (Coplen, 1993). Figure 14 illustrates concentrations of stable isotopes of oxygen and hydrogen in monitoring wells during spring and summer. Two conclusions are evident from Figure 14. First, cold and warm water signatures are evident for the spring and summer samples, with spring samples plotting to the left in Figure 14, while summer samples plot to the right. This means cold water, from snowmelt, enters the aquifer in spring, while warm water, from precipitation, enters the

aquifer in summer. This supports the conclusion that aquifer recharge occurs rapidly. Second, data for both sampling events plot along the meteoric (precipitation) water line. This means there is no evidence of fractionation (i.e. evaporation) in water reaching the aquifer. Assuming some seepage from Spring Creek reaches the aquifer, we again conclude that recharge to the aquifer is relatively rapid, since water that resides in the creek does not have time to undergo evaporation.

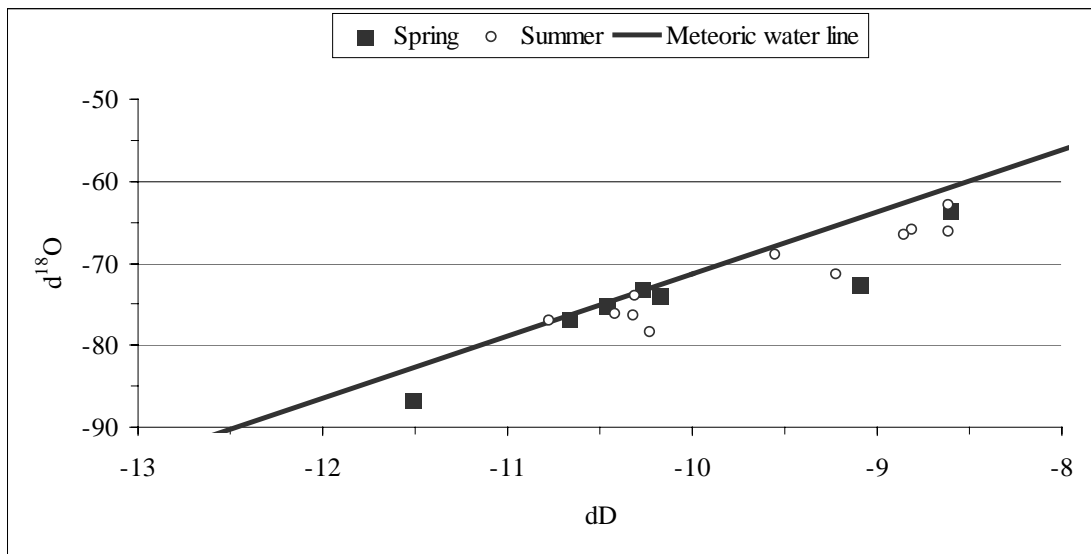


Figure 14: Concentrations of stable isotopes in monitoring wells during spring and summer, 2000.

We collected stable isotope samples in spring and summer in six wells. We compared the isotopic concentrations between the two sampling events for each well. Surprisingly, the results were mixed. Two wells showed strong, positive temperature relationships (Figure 15), while a third well showed a positive temperature relationship. This means that a cold water signature was observed in spring and a warm signature in summer, reflecting a strong positive response to snowmelt and infiltrating rainfall. The two wells with the strongest responses are located close to Spring Creek, while the third well is close to another creek north of Spring Creek. The furthest upgradient well showed the strongest response, as would be expected if seepage from Spring Creek contributes to aquifer recharge. The strong positive response near the well field may reflect surface water from Spring Creek being pulled into the aquifer due to pumping in

the public supply wells. Three wells showed a negative response, in which a cold water signature was observed in the summer and a warm signature in the spring. Each of these wells is located away from Spring Creek, and the negative response may reflect a delayed response as aquifer water moves laterally away from Spring Creek.

Recharge to the aquifer probably occurs through both soil infiltration and seepage through Spring Creek. Water level information will be useful for determining the magnitude of recharge in the aquifer. Water level recorders were deployed after spring recharge in 2000, making it impossible to evaluate the contribution of recharge from soil infiltration and creek seepage.

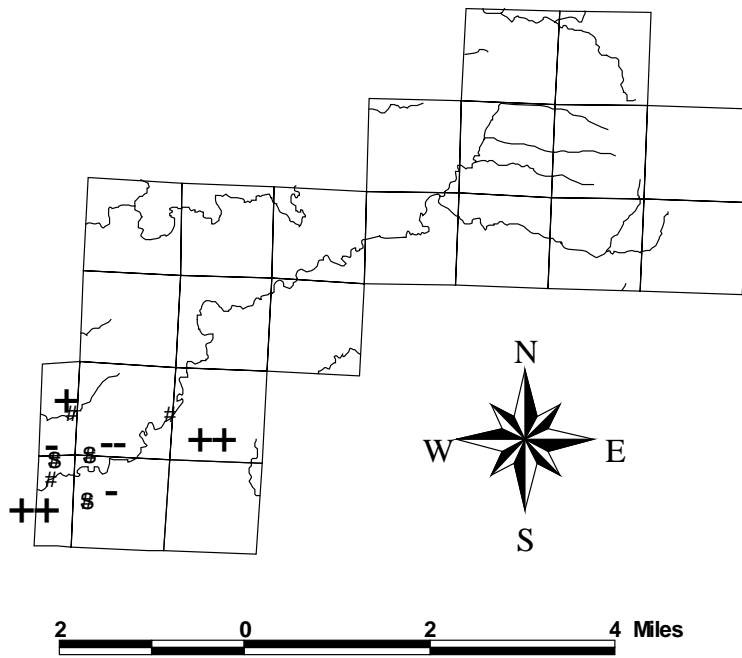


Figure 15: Locations of wells where stable isotope samples were collected during spring and summer. Wells are shown in circles. A plus sign indicates a well where a positive temperature response was detected in the well. A double plus sign indicates a stronger response than a single plus. A negative sign indicates a well where a negative temperature response was detected. A double negative sign indicates a stronger response than a single negative sign.

Water Quality

Table 3 summarizes chemical concentrations in surface water, monitoring wells, and public supply wells (complete water quality data are provided in Appendix II).

Spring Creek is characterized by high Eh, high concentrations of chloride and organic carbon, and low sulfate concentrations compared to ground water. Supply wells had high concentrations of sulfate and low concentrations of chloride. Chloride concentrations in monitoring wells were intermediate between concentrations in surface water and supply wells, suggesting aquifer recharge through both soil leaching and surface water seepage.

Nitrate is the primary chemical of concern for human health in ground water. The drinking water standard of 10 mg/l was exceeded in PS2 (public supply well 2). The nitrate concentration in Spring Creek at Site S2 was 9.8 mg/l. Figure 16 illustrates nitrate concentrations in ground water. Concentrations increase from north to south across the study area. This corresponds with an increase in Eh from north to south. Individual farming practices may have local impacts on nitrate concentrations in ground water, but we had insufficient data to compare the distribution of nitrate in the aquifer with fertilizer applications.

Correlation coefficients of nitrate with other parameters are summarized in Table 4. There was no correlation between nitrate concentrations in monitoring wells and well depth, depth to water, till thickness, or depth to the top of the aquifer. Nitrate concentrations in public supply wells, however, increased as well depth and depth to water decreased. Several factors could account for this. First, public supply wells may be mixing high-nitrate water from the upper portion of the aquifer with low-nitrate water from the lower portion of the aquifer. Second, spatial differences in farming practices may affect the nitrate distribution in individual supply wells. Third, there may be spatial differences in aquifer geochemistry which affect the fate of nitrate in the aquifer. Installation and sampling of deep monitoring wells would provide useful information for evaluating the vertical distribution of nitrate and geochemistry in the aquifer.

Differences in water quality of supply and monitoring wells may be attributable to the amount of pumping that occurs in each type of well. Monitoring wells draw water from the upper few feet of the aquifer. Supply wells are screened across a larger portion of the aquifer and closer to the bottom of the aquifer. They draw larger quantities of water than monitoring wells. With the existing monitoring network, we cannot establish a profile of oxidation-reduction conditions vertically through the aquifer. Nitrate-reducing conditions may occur in some parts of the aquifer, as evidenced by higher

Chemical	Surface water	Monitoring wells	Supply wells	p-value
Ammonia	0.04	< 0.020	-	0.826
Bicarbonate	345	265	284	0.201
Boron	35	26	-	0.098
Calcium	-	87	91	0.281
Chloride	16	11	5.0	< 0.001
Copper	1.7	1.0	-	0.135
Dissolved organic carbon	6.2	1.2	-	6 e-12
Eh	300	224	-	0.001
Iron	-	71	-	-
Magnesium	-	31	33	0.186
Nitrate	3.0	6.0	5.0	0.668
Potassium	-	2.0	3.0	0.144
Sodium	-	9.0	7.0	0.303
Sulfate	24	20	65	< 0.001
Total phosphate	< 0.20	< 0.020	-	0.596
Zinc	2.6	3.0	-	0.198

Table 3: Median chemical concentrations in surface water samples, monitoring wells, and public supply wells. P-values indicate the likelihood that concentrations are equal between the two or three types of sampling stations. Values less than 0.05 (shown in bold), are considered to represent statistically significant differences between the type of sampling stations. Concentrations are in mg/l, except for Eh (mV).

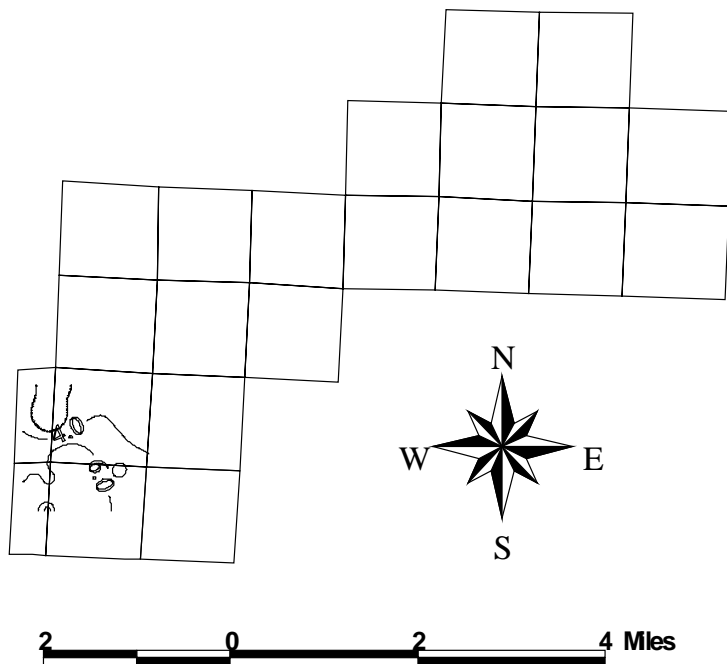


Figure 16: Contours of nitrate concentration in ground water. Concentrations are in mg/l. The contour interval is 2 mg/l.

Parameter	Surface water	Monitoring wells	Supply wells
Chloride	0.905	-0.181	0.201
Depth to aquifer top	-0.340	-0.370	-0.946
Depth to water	-	-0.307	-0.788
Eh	0.902	0.582	-
Sulfate	0.977	-0.638	-0.928
Till thickness	-	0.245	-
Total organic carbon	-0.936	-0.194	-
Total phosphate	-	0.174	-
UTM east coordinate	0.603	-0.304	-0.010
UTM north coordinate	0.469	-0.727	-0.895
Well depth	-	-0.307	-0.788

Table 4: Correlation coefficients between nitrate concentration and selected parameters. Bold values represent correlations that were significant at the 0.05 level.

concentrations of sulfate deeper in the aquifer and poor correlations between nitrate concentration and Eh for the supply wells.

There were no statistically significant differences in nitrate concentrations from monitoring wells for the winter, spring, and summer sampling event (Table 5). Eh and concentrations of chloride, however, differed between the sampling events. Eh was greatest in winter and decreased steadily through spring and into summer. The decrease during spring and summer may be related to inputs of dissolved organic carbon from Spring Creek. Concentrations of organic carbon in Spring Creek were 6.2 mg/l, compared to a median concentration of 1.2 mg/l in ground water. The carbon could stimulate microbial activity and drive the Eh down. Chloride concentrations were greatest for the May 31 sampling event and lowest for the July 24 event. These correlate with peak stream discharge (late May) and little or no stream discharge (July). Concentrations of chloride may also be related to the application of potassium chloride as a fertilizer.

Pesticides were detected at Sites S1 and S2 (Figure 17). Cumulative concentrations of all detected herbicides and herbicide metabolites were 5.59 ug/l at Site S1 and 2.26 ug/l at Site S2. Eight pesticides were detected at Site S1 and five at Site S2. Pesticides included acetochlor, metolochlor, atrazine, alachlor, and degradates of these four chemicals. Pesticides were detected in two of ten sampled monitoring wells at cumulative concentrations of 0.36 and 0.70 ug/l. Each of these wells is north of Spring

Sampling date	Nitrate	Chloride	Eh	Dissolved organic carbon
	mg/l	mg/l	mV	mg/l
March 1	5.85	11.0	282	1.10
April 18	5.80	11.2	255	1.10
May 31	4.70	13.2	220	1.35
July 24	6.40	9.67	194	1.20
p-value	0.13	0.01	10 ⁻⁷	0.37

Table 5: Median concentrations in all monitoring wells combined for four sampling events. The p-value indicates the probability that concentrations are equal between sampling events.

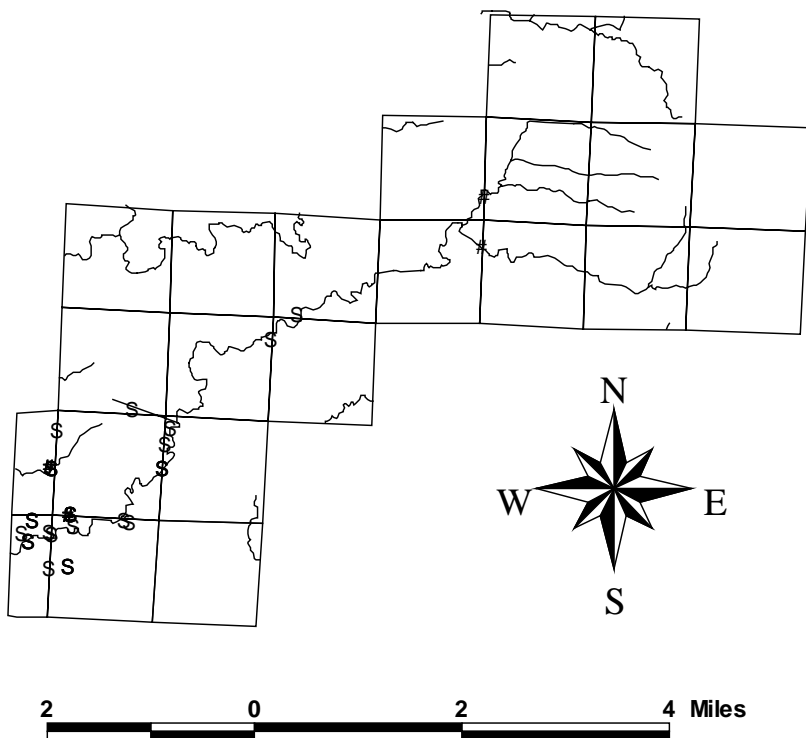


Figure 17: Location of pesticide detections (solid circles).

Creek. These wells were sampled in May, at a time when measured stream seepage was greatest. Surface water is a potential source for these pesticides due to high pesticide concentrations in the upgradient surface water samples and the likelihood of stream seepage to ground water. Pesticide data are included in Appendix II.

Summary

1. The magnitude of aquifer recharge attributable to seepage from Spring Creek is unknown. Approximately 8 million cubic feet of water seeped through Spring Creek in 2000. This was 50 percent of total streamflow for the year. Spring Creek may be a source of chloride, organic carbon, and agricultural herbicides to ground water.
2. The aquifer appears to respond rapidly to recharge. No fractionation of water was observed using stable isotopes. Isotopic analysis of ground water also showed strong temperature signatures, indicating rapid recharge of cold meltwater in spring and warm precipitation in summer. The Eh and chloride concentrations of ground water also varied seasonally, reflecting inputs of carbon and chloride from different recharge sources.
3. Nitrate concentrations increased from north to south. This increase correlates with an increase in Eh from north to south in the aquifer. At this time, there is insufficient data to determine the oxidation-reduction (redox) status of ground water vertically within the aquifer. Differences in chemistry of monitoring and supply wells suggests there are vertical differences in the redox status of the aquifer, although the observed differences may also be related to local farming practices.

For long-term monitoring to succeed, we need to better understand mechanisms of recharge, contributions from different recharge sources, and the distribution of redox conditions within the aquifer. This information helps understand the importance of including the entire Spring Creek watershed in the wellhead protection area, can assist in locating additional public supply wells, and help us understand the relationships between farming practices and trends in ground water quality. In Appendix III, we provide recommendations for a long-term monitoring program in the Verdi WPA.

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Appendix I – Reporting Limits and Laboratory Methods

Chemical	Reporting Limit	Laboratory Method
Stable isotopes		
Inorganics		
Alkalinity	1 mg/l	Titration
Aluminum	0.049 mg/l	ICP
Ammonia	0.020 mg/l	Colorometric
Boron	0.13 mg/l	ICP
Cadmium	0.0019 mg/l	ICP
Calcium	0.055 mg/l	ICP
Chloride	0.10 mg/l	Ion Chromatography
Chromium	0.0034 mg/l	ICP
Copper	0.0055mg/l	ICP
Dissolved organic carbon	0.50 mg/l	Dohrman carbon analyzer
Dissolved oxygen	0.010 mg/l	Field meter
Eh	1 mV	Field meter
Fluoride	0.20 mg/l	Ion Chromatography
Iron	0.0034 mg/l	ICP
Lead	0.024 mg/l	ICP
Magnesium	0.020 mg/l	ICP
Manganese	0.00070 mg/l	ICP
Nickel	0.0061 mg/l	ICP
Nitrate	0.020 mg/l	Cadmium reduction
pH	0.1 pH unit	Field meter
Phosphorus	0.030 mg/l	ICP
Potassium	0.118 mg/l	ICP
Sodium	0.060 mg/l	ICP
Specific conductance	0.1 mmho/cm	Field meter
Sulfate	0.10 mg/l	Ion chromatography
Temperature	0.1 °C	Field meter
Total organic carbon	0.5 mg/l	Dohrman carbon analyzer
Total phosphorus	0.020 mg/l	ICP
Zinc	0.0027 mg/l	ICP

APPENDIX II¹ – Chemical and Physical Information for Sampling Points

General Information

StationID	Unique No.	UTM-east	UTM-north	Type
S3	-	228199	4903976	surface water
S5	-	226506	4901837	surface water
S4	-	226553	4902283	surface water
S1	-	231537	4906115	surface water
S2	-	231490	4905316	surface water
PS1	149160	224781	4900837	public supply well
PS2	149161	224748	4900313	public supply well
PS3	149162	224312	4900869	public supply well
PS4	149163	224748	4900877	public supply well
PS5	149182	224860	4902473	public supply well
M1	609978	224421	4900741	monitoring well
M2	609979	224480	4901078	monitoring well
M3	609981	224777	4901886	monitoring well
M4	609982	225069	4901158	monitoring well
M5	609983	226487	4901873	monitoring well
M6	609987	225044	4900363	monitoring well
M7	633539	225994	4901024	monitoring well
M8	633540	225125	4900957	monitoring well
M9	637707	225903	4901061	monitoring well
M10	637717	226540	4902235	monitoring well

Physical Information

Unique No. or Station ID	Depth to water	Well depth	Depth to aquifer bottom	Depth to aquifer top	Till thickness	Depth to screen top	Depth to screen bottom
	feet	Feet	feet	feet	feet	feet	feet
S3	0	0	-	-	-	-	-
S5	0	0	-	-	-	-	-
S4	0	0	-	-	-	-	-
S1	0	0	-	-	-	-	-
S2	0	0	-	-	-	-	-
149160	29	62	62	28	26	47	62
149161	22	58	58	22	22	45	57
149162	28	60	52	35	30	47	60
149163	30	67	67	37	27	54	67
149182	19	69	69	42	24	54	69
609978	11	39	37	9	7	27	37
609979	28	63	61	35	23	53	63
609981	21	67	67	39	10	57	67
609982	31	67	68	38	25	-	-
609983	20	41	39	36	11	31	41
609984	-	70	-	-	34	-	-
609985	-	70	-	-	57	-	-
609986	-	70	-	-	51	-	-
609987	40	66	64	57	57	56	66
609988	-	70	-	-	63	-	-
633539	-	-	-	-	-	-	-
633540	-	-	-	-	-	-	-
637707	24	53	53	29	27	43	53
637717	11	45	44	37	33	-	-

Anions

Unique No. or StationID	Date	Nitrate	Chloride	Phosphate	Sulfate	Bicarbonate
		mg/l	mg/l	mg/l	mg/l	mg/l
S3	5/25/00	2.2	16.19	<0.20	24.0	-
S5	5/25/00	1.2	16.22	<0.20	24.4	-
S4	5/25/00	3.5	16.04	<0.20	24.7	-
S1	5/25/00	3.0	17.2	<0.20	24.0	-
S2	5/25/00	9.8	18.94	<0.20	32.5	345
149160	-	6.0	14.0	-	65.0	-
149161	-	11.0	5.0	-	29.0	-
149162	-	4.0	4.0	-	84.0	-
149163	-	5.0	5.0	-	61.0	-
149182	-	nd	4.0	-	85.0	-
609978	3/1/00	8.3	8.5	<0.20	17.0	259
609978	4/18/00	8.4	7.80	<0.20	15.7	270
609978	5/31/00	4.3	12.46	<0.20	19.2	258
609978	7/24/00	9.6	7.2	<0.20	15.0	268
609979	3/1/00	5.5	13.9	<0.20	20.0	258
609979	4/18/00	5.8	13.73	<0.20	20.0	279
609979	5/31/00	5.1	14.00	<0.20	21.2	263
609979	7/24/00	5.2	13.5	<0.20	21.2	265
609981	3/1/00	< 0.5	9.2	<0.20	23.5	287
609981	4/18/00	< 0.5	8.99	<0.20	23.3	278
609981	5/31/00	< 0.5	9.21	<0.20	23.6	268
609981	7/24/00	< 0.5	8.6	<0.20	23.0	186
609982	3/1/00	7.2	14.1	<0.20	20.9	-
609982	4/18/00	-	13.35	<0.20	19.7	291
609982	5/31/00	7.5	14.06	<0.20	20.2	280
609982	7/24/00	9.6	13.5	<0.20	20.3	-
609982	8/14/00	6.8	-	-	-	-
609983	3/1/00	4.2	12.8	<0.20	19.6	281
609983	4/18/00	2.6	14.66	<0.20	18.7	285
609983	5/31/00	1.4	16.56	<0.20	20.5	249
609983	7/24/00	0.7	16.2	<0.20	22.6	265
609984	-	-	-	-	-	-
609985	-	-	-	-	-	-
609986	-	-	-	-	-	-
609987	3/1/00	6.2	8.0	<0.20	13.8	273
609987	4/18/00	6.1	7.35	<0.20	12.8	280
609987	5/31/00	6.1	8.14	<0.20	14.0	259
609987	7/24/00	6.4	9.1	<0.20	14.8	262
609988	-	-	-	-	-	-
633539	7/24/00	6.2	7.4	<0.20	14.3	272
633540	7/24/00	7.1	10.3	<0.20	15.5	280
637707	-	-	-	-	-	-
637717	-	-	-	-	-	-

Nonionic chemicals

Unique No. or StationID	Date	Kjeldahl nitrogen	Organic carbon _{total}	Phosphorus	Organic carbon _{dissolved}	Ammonia
		mg/l	mg/l	mg/l	mg/l	mg/l
S3	5/25/00	0.67	6.2	-	6.2	0.05
S5	5/25/00	0.48	6.6	-	6.4	0.04
S4	5/25/00	0.77	5.9	-	6.3	0.04
S1	5/25/00	0.50	5.5	-	5.7	0.04
S2	5/25/00	0.81	3.6	0.020	3.4	0.04
149160	-	-	-	-	-	-
149161	-	-	-	-	-	-
149162	-	-	-	-	-	-
149163	-	-	-	-	-	-
149182	-	-	-	-	-	-
609978	3/1/00	< 0.20	1.1	0.080	4.2	0.06
609978	4/18/00	< 0.20	1.1	0.050	0.8	0.03
609978	5/31/00	0.24	1.9	0.080	1.8	0.03
609978	7/24/00	< 0.20	0.9	0.050	0.9	0.02
609979	3/1/00	< 0.20	0.8	< 0.020	1.4	0.02
609979	4/18/00	< 0.20	1.0	< 0.020	1.3	0.03
609979	5/31/00	0.20	1.1	< 0.020	1.1	0.02
609979	7/24/00	0.20	1.0	0.020	1.6	0.02
609981	3/1/00	< 0.20	0.8	0.020	0.9	0.16
609981	4/18/00	0.24	0.9	< 0.020	1.1	0.15
609981	5/31/00	< 0.20	1.0	< 0.020	1.2	0.15
609981	7/24/00	< 0.20	0.8	0.020	0.9	0.14
609982	3/1/00	< 0.20	1.0	< 0.020	1.1	0.02
609982	4/18/00	-	-	-	-	-
609982	5/31/00	0.38	1.3	0.020	1.5	0.02
609982	7/24/00	< 0.20	1.1	0.050	1.8	0.02
609982	8/14/00	0.20	1.3	< 0.020	1.2	0.03
609983	3/1/00	< 0.20	1.1	< 0.020	1.1	0.05
609983	4/18/00	< 0.20	1.1	< 0.020	1.3	0.04
609983	5/31/00	0.27	1.4	< 0.020	2.0	0.03
609983	7/24/00	< 0.20	1.7	0.020	1.5	0.02
609984	-	-	-	-	-	-
609985	-	-	-	-	-	-
609986	-	-	-	-	-	-
609987	3/1/00	< 0.20	0.8	0.030	0.8	0.06
609987	4/18/00	< 0.20	0.9	< 0.020	0.8	0.03
609987	5/31/00	0.22	0.9	< 0.020	1.2	0.03
609987	7/24/00	0.26	0.8	0.020	0.7	0.03
609988	-	-	-	-	-	-
633539	7/24/00	0.23	1.0	0.040	1.8	0.03
633540	7/24/00	0.23	1.3	0.050	1.1	0.04
637707	-	-	-	-	-	-
637717	-	-	-	-	-	-

Field parameters

Unique No. or StationID	Date	Dissolved oxygen	Eh	pH	Specific conductance	Temperature
		mg/l	mV		umhos/cm	°C
S3	5/25/00	13.12	300	8.21	725	16.91
S5	5/25/00	13.09	300	8.30	724	18.69
S4	5/25/00	13.97	307	8.29	752	18.52
S1	5/25/00	14.47	297	8.23	766	18.90
S2	5/25/00	11.38	315	8.04	852	17.57
149160	-	-	-	7.00	700	-
149161	-	-	-	7.00	650	-
149162	-	-	-	7.00	750	-
149163	-	-	-	7.00	650	-
149182	-	-	-	7.00	800	-
609978	3/1/00	3.23	291	7.32	673	9.34
609978	4/18/00	9.40	257	7.21	777	8.77
609978	5/31/00	4.05	220	6.11	633	10.61
609978	7/24/00	5.18	224	-	663	10.43
609979	3/1/00	3.18	279	6.94	662	8.88
609979	4/18/00	9.52	253	7.11	806	8.81
609979	5/31/00	3.17	225	6.72	671	13.33
609979	7/24/00	3.78	230	-	677	9.76
609981	3/1/00	0.20	178	6.90	641	8.80
609981	4/18/00	6.63	144	7.06	770	8.61
609981	5/31/00	0.22	145	6.50	658	9.80
609981	7/24/00	0.27	127	-	651	11.01
609982	3/1/00	4.18	285	6.85	737	8.32
609982	4/18/00	9.62	285	7.10	853	8.15
609982	5/31/00	3.94	222	6.36	729	9.37
609982	7/24/00	3.96	217	-	735	10.59
609982	8/14/00	-	-	-	-	-
609983	3/1/00	1.73	246	7.14	677	8.52
609983	4/18/00	12.45	229	7.17	792	8.71
609983	5/31/00	4.90	220	6.65	657	10.05
609983	7/24/00	1.02	159	-	665	10.84
609984	-	-	-	-	-	-
609985	-	-	-	-	-	-
609986	-	-	-	-	-	-
609987	3/1/00	5.39	330	7.19	638	8.44
609987	4/18/00	12.16	288	7.17	743	8.47
609987	5/31/00	4.97	215	6.84	632	9.65
609987	7/24/00	4.56	223	-	631	11.95
609988	-	-	-	-	-	-
633539	7/24/00	4.24	171	-	625	10.12
633540	7/24/00	6.35	165	-	707	10.77
637707	-	-	-	-	-	-
637717	-	-	-	-	-	-

Metals and trace elements

Unique No. or StationID	Date	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Boron	Copper	Zinc
		mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l
S3	5/25/00	-	-	-	-	-	26.4	35.7	1.72	2.76
S5	5/25/00	-	-	-	-	-	33.4	30.3	3.81	3.85
S4	5/25/00	-	-	-	-	-	30.9	38.5	1.71	2.28
S1	5/25/00	-	-	-	-	-	19.7	28.4	1.57	2.13
S2	5/25/00	-	-	-	-	-	29.4	42.6	1.64	2.64
149160	-	102	32	6.0	3.0	nd	nd	-	-	-
149161	-	83	31	7.0	2.0	nd	nd	-	-	-
149162	-	95	34	8.0	2.0	nd	nd	-	-	-
149163	-	86	31	7.0	2.0	nd	nd	-	-	-
149182	-	91	27	12.0	3.0	nd	nd	-	-	-
609978	3/1/00	87	32	11.8	3.4	165	-	13.9	1.51	2.87
609978	4/18/00	83	32	6.1	3.1	64	-	30.1	1.07	3.53
609978	5/31/00	-	-	-	-	-	-	25.8	2.84	2.41
609978	7/24/00	-	-	-	-	-	-	-	-	-
609979	3/1/00	88	35	6.5	2.6	39.2	-	12.2	0.69	6.18
609979	4/18/00	84	34	6.5	2.6	46.3	-	33.6	2.73	4.61
609979	5/31/00	-	-	-	-	-	-	25.6	1.46	8.16
609979	7/24/00	-	-	-	-	-	-	-	-	-
609981	3/1/00	90	32	8.5	2.1	598	-	28.9	0.73	2.94
609981	4/18/00	85	31	8.3	2.0	820	-	50.6	0.82	2.29
609981	5/31/00	-	-	-	-	-	-	41.5	0.82	9.51
609981	7/24/00	-	-	-	-	-	-	-	-	-
609982	3/1/00	95	38	7.7	2.6	113	-	< 10	0.76	5.87
609982	4/18/00	-	-	-	-	-	-	-	-	-
609982	5/31/00	-	-	-	-	-	-	22.5	1.25	1.86
609982	7/24/00	-	-	-	-	-	-	-	-	-
609982	8/14/00	-	-	-	-	-	-	-	-	-
609983	3/1/00	89	33	12.6	4.4	71.1	-	10.3	1.12	3.24
609983	4/18/00	81	33	9.8	4.5	136	-	30.3	2.46	2.57
609983	5/31/00	-	-	-	-	-	-	23.5	1.75	9.85
609983	7/24/00	-	-	-	-	-	-	-	-	-
609984	-	-	-	-	-	-	-	-	-	-
609985	-	-	-	-	-	-	-	-	-	-
609986	-	-	-	-	-	-	-	-	-	-
609987	3/1/00	79	33	9.1	1.9	32.3	-	< 10	8.04	1.98
609987	4/18/00	-	-	-	-	-	-	-	-	3.06
609987	5/31/00	100	22	15.4	7.2	Nd	-	77.4	3.29	9.26
609987	7/24/00	-	-	-	-	-	-	-	-	-
609988	-	-	-	-	-	-	-	-	-	-
633539	7/24/00	-	-	-	-	-	-	-	-	-
633540	7/24/00	-	-	-	-	-	-	-	-	-
637707	-	-	-	-	-	-	-	-	-	-
637717	-	-	-	-	-	-	-	-	-	-

Pesticides

StationID or Unique No.	Sample Date	Parameter Name	Quantity (ug/l)
S1	25-May-00	Acetochlor	0.06
S1	25-May-00	Acetochlor ESA	1.38
S1	25-May-00	Acetochlor Oxanilic Acid	2.10
S1	25-May-00	Alachlor ESA	0.20
S1	25-May-00	Atrazine	0.09
S1	25-May-00	Deethylatrazine	0.07
S1	25-May-00	Hydroxy-Atrazine	0.58
S1	25-May-00	Metolachlor ESA	1.11
S2	25-May-00	Acetochlor	0.06
S2	25-May-00	Acetochlor ESA	0.78
S2	25-May-00	Acetochlor Oxanilic Acid	0.71
S2	25-May-00	Hydroxy-Atrazine	0.29
S2	25-May-00	Metolachlor ESA	0.42
609981	31-May-00	Alachlor ESA	0.24
609982	31-May-00	Atrazine	0.05
609982	31-May-00	Deethylatrazine	0.07
609982	31-May-00	Metolachlor ESA	0.70

¹ nd = not detected; reporting limit unknown

Appendix III - Monitoring Plan for the Verdi Wellhead Protection Area

The monitoring network installed in 2000 will be a useful tool for evaluating effectiveness of BMPs once a cohesive, long-term monitoring strategy is developed. The following monitoring plan outlines a monitoring network for the Verdi WPA. Due to resource constraints, the MPCA cannot commit to activities beyond July 1, 2001. Because much of the monitoring plan may be implemented at the local level, we include a discussion of Quality Assurance issues.

Network Consolidation

The existing network includes ten monitoring wells, five public supply wells, and five surface water locations. MPCA samples eight of the monitoring wells and the surface water locations, while the LPRWSD samples the public supply wells and two of the monitoring wells. All components of this network should be joined into a single network that conforms to the following guidelines.

- All samples are collected simultaneously at specified times during the year.
- All samples are collected using documented sampling procedures. We recommend using procedures outlined in MPCA (1998c). Procedures include sample purging, field measurement, sample collection, and application of consistent Quality Assurance and Quality Control (QA/QC) methods.
- Laboratory methods are applied uniformly. Preferably, all samples are sent to the same laboratory for analysis. If this does not occur, each laboratory must submit a QA/QC plan to the MPCA and LPRWSD.
- Individual water quality samples (not blended water) are required from public water supply wells.
- All data are entered into a central database. Minimal fields in the database include a unique well identifier, utm locations, sampling date, field measurements, and nitrate concentration. All wells must have drilling logs.
- Establish Geographic Information System coverages for all sampling points, agricultural management systems, areas in the CRP, and potential pollution sources. Pollution sources include existing feedlots, abandoned feedlots, fields with manure fertilizer, and fields with commercial fertilizer.

Water Quality Sampling Schedule

Quarterly sampling occurs in early March, mid-May, August, and late October. All samples are collected within a three-day period. Sample parameters include field measurements of dissolved oxygen, specific conductivity, oxidation-reduction potential, pH, and temperature, and laboratory samples for nitrate and chloride.

Physical Measurements

Continuous water level recorders are deployed in two wells throughout the year. Water level measurements are recorded at a minimum interval of one hour. Data are downloaded prior to March 1 of each year. Stream gauges are deployed immediately after ice-out at two upgradient locations and two downgradient locations on Spring Creek. The two upgradient locations are on Highway 2 and include Site S1 (T109-R46-S10-SE) and Site S2 (T109-R46-S15-NE). The downgradient locations include one gauge on Highway 1 (T109-R46-S29-NW) and another at T109-R46-S20-NE. Water elevations are recorded at a minimum interval of 30 minutes. Data are collected between ice-out in spring and late summer, when stream discharge is typically zero. Ideally, precipitation data are collected within the WPA, but precipitation data from the Pipestone National Weather Service Station can be used.

Additional Wells

Currently, all monitoring wells are completed in the upper portion of the aquifer. Supply wells are completed in the aquifer, but due to pumping, these wells probably draw water from shallower portions of the aquifer. Deeper monitoring wells are needed to provide additional geochemical information about the aquifer. This information helps us understand the denitrification potential within the aquifer and can be used to place future supply wells or guide withdrawals from supply wells. A minimum of two wells are needed, although four wells are preferred.

Information Needs

The monitoring network is designed to assess impacts of land use activities. Consequently, detailed information is needed regarding agricultural management systems. This includes information on use of organic and inorganic fertilizers, pesticides, tillage and application practices, crops grown, and nitrogen balance calculations. This information should be compiled into an accessible electronic format. The MDA FANMAP work has provided very useful information on land use within the watershed. A variety of LCMR research activities in Southwest Minnesota provide useful information on land use. This includes modeling of nitrogen leaching. Historical land use information can be collected using aerial photographs and by conducting interviews with local farmers and extension agents.

Reporting

An annual report summarizes water quality, water level, and stream discharge information for the year. The annual report includes a monitoring plan for the coming year. The report includes information on changes in other aspects of the project. For example, changes in agricultural management practices that potentially affect monitoring results would be noted in the annual report.

Supplemental Needs

The following activities provide information to improve our understanding of water quality and recharge in the aquifer. They are beyond the scope of the current project, but can be implemented in the future.

1. Ground water age dating – Initial data suggests that recharge to the Verdi aquifer occurs rapidly. Samples collected for Chlorofluorocarbons (CFCs) can be used to date ground water with an accuracy of about one year. The United States Geological Survey analyzes these samples for about \$1000 a sample. Two samples would be collected, one from a shallow monitoring well and one from a deep monitoring well. If deep monitoring wells are not drilled, a supply well can be used, although the information is more speculative since it is not known if the water is coming from the top or bottom of the aquifer.

2. Leaching models – we have good information on concentrations of chloride in surface water and in the aquifer. Changes in chloride concentration of ground water correlate with discharge in Spring Creek. The contribution of stream discharge to ground water recharge is unknown but can be approximated using chloride as a conservative tracer. To make these calculations, we need to know concentrations of chloride in soil and vadose zone leachate. Direct measurement of leaching (for example, with lysimeters) is probably cost prohibitive. Leaching models can be used to provide estimates of chloride concentrations in leachate. Nitrate can also be used in these mixing calculations, but nitrate may undergo transformations during leaching and stream seepage. Estimating these transformation rates is probably less accurate than predicting chloride concentrations in leachate.
3. Ground water models – A ground water model was developed for the wellhead protection area. The model was used to identify a ten-year time of travel area and to help delineate the boundaries of the wellhead protection area. The model should be refined using existing data on stream discharge. The model can then be expanded to include contaminant transport modeling. Unsaturated and saturated zone results can be linked to estimate nitrate leaching to and fate within the aquifer.
4. Pesticide sampling – Pesticides were detected at relatively high concentrations in Spring Creek during a May sampling event. Pesticides were detected in two monitoring wells, although at much lower concentrations. An additional round of sampling should be conducted in May of 2001 to verify the 2000 results.

MPCA Activities during 2001

The MPCA will collect water quality samples from the monitoring network in March and May of 2001. We will deploy water level recorders in two wells and at two to four surface water locations. We will download water level information. In early 2002, we will produce an annual report summarizing water level and water quality information for 2001.

Table A1 outlines suggested monitoring activities for 2001. MPCA cannot commit to activities beyond July 1, 2001. By May, 2001, we will identify resources available for maintaining the monitoring network. MPCA will attempt to ensure that the

activities outlined in Columns 2 and 3 of Table A1 are completed. This may consist of transferring responsibilities to local SWCD and LPRWSD staff.

Activity	MPCA will conduct	MPCA cannot commit	MPCA will not conduct
Water quality sampling in March and May	X		
Water quality sampling in August and October		X	
Water level measurements in two wells	X		
Stream flow gauging	X ¹		
Installation of two additional wells	X ²		
Annual report ³	X		
Water quality database development		X	
Network consolidation		X ⁴	
CFC sampling			X
Pesticide sampling in May	X ⁵		
Ground water modeling			X
Soil leachate modeling			X

¹ Assumes assistance from MPCA surface water staff

² MPCA will match funding, up to \$2000, for installation of additional wells

³ The annual report is typically completed within three months of the last sampling event.

⁴ MPCA will work with LPRWA staff to develop a consolidated monitoring network

⁵ Select sampling locations only

Table A1: Summary of 2001 monitoring activities.