

STATE OF SOUTH DAKOTA
William J. Janklow, Governor

DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
Steven M. Pirner, Secretary

DIVISION OF FINANCIAL AND TECHNICAL ASSISTANCE
David Templeton, Director

GEOLOGICAL SURVEY
Derric L. Iles, State Geologist

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**RESULTS OF MONITORING FROM 1989 THROUGH 1997
FOR THE
STATEWIDE GROUND WATER QUALITY MONITORING NETWORK**

by

TOM RICH

Akeley-Lawrence Science Center
University of South Dakota
Vermillion, South Dakota

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INTRODUCTION

The statewide ground water quality monitoring effort is an endeavor to monitor sensitive aquifers in South Dakota for non-point sources of contamination and long term trends in water quality. The purpose of this report is to describe monitoring activities and results related to the statewide ground water quality monitoring effort for the years 1989 through 1997. Figure 1 is a map of South Dakota on which the locations of the monitored aquifers are plotted. This figure shows the entire monitoring network as of 2001 even though this report provides results of monitoring activities only through 1997. Therefore, results from wells installed after 1996 are not discussed in this report. This means that there are no results in this report from the Arikaree, Chapelle Creek, Coteau Lakes, Cow Creek, Elm, Okobojo Creek, and Spring Creek aquifers. It is emphasized that, due to limited information in many areas, the aquifer boundaries shown on this figure are very approximate and should not be used for purposes outside of this report. Figure 1 also shows the locations of the wells comprising the monitoring network. The aquifer, location, and depth corresponding to each well are indicated on table 1.

The statewide ground water quality monitoring network has been designed to examine non-point-source pollution and ambient ground water quality. The goal of the statewide ground water quality monitoring effort is to maintain and modify as necessary ground water quality monitoring activities that regularly and systematically assess the present water quality, impact of agricultural chemicals on ground water, and long-term trends in water quality in sensitive aquifers. This effort includes the installation and maintenance of a statewide network of monitoring sites, performing analyses of samples collected from wells comprising these sites, and reporting. The aquifers being monitored cover much of South Dakota and are among the most likely to be impacted by human activities because of their near surface occurrence combined with overlying land use. Emphasis has been placed on monitoring for health related aspects of water quality and on monitoring for non-point sources of ground water contamination. Analytes include pesticides, pesticide transformation products, nitrate plus nitrite as nitrogen, common inorganic constituents, volatile organic compounds, radionuclides, cyanide, and trace metals. Monitoring sites are located away from known point sources of pollution, such as animal feeding areas, septic tanks, and underground storage tanks.

Contained within this report are methods of aquifer and monitoring site selection, monitoring well installation and development procedures, and sampling protocol. The geographic and hydrogeologic settings of the monitored aquifers are also discussed. A discussion of the water quality by major chemical constituent groups is presented, as is the water quality of each monitored aquifer. Finally, a summary of the water quality in shallow aquifers in the state is presented along with recommendations for additional work. The purpose of the effort is to monitor and describe water quality of sensitive aquifers. Because this report is a comprehensive description of water quality in these aquifers, anyone whose activities may impact or who uses the water monitored by the statewide monitoring effort may find this report to be useful. Information in the report may be of interest to county agents, regulators, manufacturers and users of pesticides and fertilizers, environmental groups, research organizations, and users of water from the monitored aquifers.

PREVIOUS INVESTIGATIONS

Prior to the ground water quality monitoring effort described in this report, there had been no comprehensive statewide effort to systematically monitor shallow, sensitive aquifers. However, there had been several individual projects conducted by the Geological Survey and Ground Water Quality Programs of the Department of Environment and Natural Resources which had produced information on organic and inorganic water quality of some shallow aquifers in the state. In 1989 and 1990, samples were analyzed only for common inorganic parameters. The performance of analyses for pesticides was initiated in 1991 on samples from the Big Sioux aquifer. By 1997, water from 18 aquifers was being analyzed for pesticides as part of the statewide ground water quality monitoring effort. The list of pesticides to be analyzed was established in consultation with the South Dakota Department of Agriculture. This list of pesticides has been modified for individual wells and aquifers on the basis of local pesticide use. In 1993, two transformation products (decay products) of atrazine were added to this list. An extended group of parameter lists for analysis consisting of inorganic constituents, volatile organic compounds, trace metals, radionuclides, pesticides, two atrazine transformation products, and cyanide was established in 1994.

None of the previous projects examined as many water quality parameters as the current statewide ground water quality monitoring effort. Some of the monitoring sites used in past investigations were incorporated into the current monitoring network, but most monitoring sites now used were established specifically for the statewide ground water quality monitoring effort. New monitoring sites and aquifers were added to the project every year from 1994 to 1997. By the end of 1997, there were 124 ground water quality monitoring wells at 68 sites in 18 shallow aquifers across the state from which samples had been collected. At the present time, there are 145 wells at 80 monitoring sites in 25 aquifers comprising the statewide ground water quality monitoring network.

METHODS

Well Identification

The format for a typical well identifier is R20-89-54. "R20" refers to the drilling rig that was used to advance the boring in which the well was constructed. The "54" and the "89" indicate that the well was constructed in the 54th boring drilled by that rig in 1989. Most wells were initially sampled within a year of their construction. While the data generated during the course of the project have been summarized for presentation in this report, raw data are available from the Geological Survey Program of the Department of Environment and Natural Resources upon request.

Aquifer and Site Selection

Surficial aquifers across South Dakota were considered for inclusion in the monitoring effort. The aquifers on figure 1 were those that could be accommodated with money available for

monitoring network installation. The aquifers on figure 1 also had to be sufficiently thick near land surface in a location accessible to the drilling equipment of the Geological Survey Program.

It was essential that each site be representative of typical land use over the aquifer. In addition, it was necessary to select sites that were distant from any known or suspected point source of pollution. Whenever possible, monitoring sites were placed in portions of aquifers that were thick enough to allow for installation of two wells whose screened intervals do not overlap vertically. Wells paired in this fashion are referred to, in the rest of this report, as “nested wells.”

Drilling and Monitoring Well Installation

A Mobile B61-D hollowstem auger rig was used to drill borings for the installation of water quality monitoring wells. Monitoring wells were generally constructed using 4-inch diameter, schedule 40, polyvinyl chloride (PVC) casing and screen. Some of the older water quality monitoring wells incorporated into the statewide ground water quality monitoring network are 2 inches in diameter and of PVC construction. Well depths and screened intervals were determined using existing lithologic data and by drilling at each site. Each monitoring site features a well with a screened interval that intersects, or is very near, the water table. Where a sufficient thickness of aquifer was present, a second well was installed with a screened interval below the water table and below the depth of the adjacent shallow well. Wells were located in right of ways adjacent to public roads.

Standard well design includes a filter pack consisting of native sediment or quartz sand, or both. The filter pack is overlain by a bentonite seal which prohibits infiltration of surface water through the borehole annulus. Cement is set into place above the bentonite seal to stabilize the well casing. Wells were completed with a short length of casing extending above ground and were covered with a locking steel well protector. Figure 2 is a generalized diagram of a typical monitoring well. The well construction and general geology of each site are presented schematically in appendix A. Lithologic logs for the borings and well construction information are on file at the Geological Survey Program.

Monitoring Well Development and Sampling

Dedicated submersible pumps are currently used for development and sampling of wells in the statewide ground water quality monitoring network. Many of the older wells in the network were developed with a jet pump attached to dedicated PVC pipe with a check valve attached to the bottom of the pipe. Numerous volumes of water are removed from wells during well development. Temperature, pH, and electrical conductivity measurements are taken during development. Development procedures are generally terminated after consecutive readings of these parameters have indicated stabilization, and the well water is relatively clear.

During a sampling event, water within a monitoring well is evacuated through the pumping system. During evacuation of wells completed in sediments that are of moderate to high hydraulic conductivity, temperature, pH, and electrical conductivity are measured until they have

stabilized. Wells are considered to have stabilized after three consecutive readings taken 5 minutes apart indicate constant temperature, pH, and electrical conductivity. After stabilization and a minimum of 3 well volumes of water have been evacuated, a sample is collected.

In sediments of low hydraulic conductivity (which have low rates of water yield), it is not always possible to remove 3 or more well volumes in a reasonable amount of time. In these cases, the well is pumped “dry.” Temperature, pH, and electrical conductivity are measured as water re-enters the well. The sample is collected once a sufficient volume of water has re-entered the well.

Standard sampling protocol also specifies that samples collected for the analysis of inorganic parameters, radionuclides, and cyanide are passed through a 0.45 micron filter. Care is taken to prevent aeration of samples to be tested for volatile organic compounds. To provide for quality assurance and quality control, blank samples were sent to the analytical laboratory with the samples to be tested for volatile organic compounds.

Sampling Frequency

All wells in the statewide ground water quality monitoring network are currently subject to sampling once per year. An attempt is made to sample each well as close to the same time each year as possible. Prior to 1994, wells monitoring the Big Sioux aquifer were sampled several times per year. Samples collected on an annual basis are analyzed for pesticides and common inorganic parameters. Trace metals, radionuclides, and cyanide analyses are currently performed once every 5 years. Volatile organic compounds are also analyzed once every 5 years, but in only about 25 percent of the wells in an aquifer.

Wells which commonly yield samples containing detectable concentrations of pesticides and high nitrate concentrations may be placed on a list of wells to be sampled four times per year. The four samples consist of one annual sample and three other samples that were analyzed only for pesticides, nitrate plus nitrite as nitrogen, and ammonia or, alternatively, just for nitrate plus nitrite as nitrogen and ammonia. The list of wells that are sampled an additional three times per year is periodically reviewed and modified.

Analytical Laboratory

Samples collected from 1989 through 1995 were analyzed at the University of Iowa Hygienic Laboratory. The South Dakota Department of Health Laboratory performed analyses of samples collected in 1996 and 1997.

GEOGRAPHIC AND HYDROGEOLOGIC SETTING OF MONITORED AQUIFERS

As a northern plains state located in a mid-continental position, South Dakota experiences large seasonal and daily differences in temperature. Average annual precipitation ranges from

less than 14 inches in the northwest to more than 24 inches in the southeastern part of the state. Most of the precipitation occurs as rainfall during spring and early summer, although heavy snowfall accumulation can occur, especially in the northern part of the state. During the period reported on herein (from 1989 through 1997), the state generally received precipitation in excess of normal, especially in 1991 and 1993. Shallow aquifers in South Dakota are generally recharged by direct infiltration of precipitation and by direct discharge from other aquifers. The monitored aquifers discharge into rivers, streams, springs, other aquifers, and irrigation systems (or other wells), and by evapotranspiration.

There are four general types of surficial aquifers within which wells have been constructed for the monitoring network. These types are outwash, alluvial, eolian, and bedrock. Outwash aquifers consist mainly of sand and gravel that were deposited by glacial meltwater. Alluvial aquifers can consist of a wide variety of materials ranging in size from clay to gravel that are deposited by modern streams and rivers. The one eolian aquifer monitored for this project consists of windblown sediment that is typically fine grained sand. Bedrock aquifers monitored for this project consist generally of unconsolidated to semiconsolidated sand and silty sand that were deposited by ancient streams and rivers.

The two bedrock aquifers in the monitoring network are the Arikaree and Ogallala aquifers, both of which are located in the south-central part of the state. The Ogallala aquifer is the only bedrock aquifer for which analytical data were generated in the time period covered by this report. The only eolian aquifer monitored in the statewide ground water quality monitoring effort is the Sand Hills aquifer located in the south-central part of the state. This aquifer lies directly on parts of the Ogallala aquifer. The four alluvial aquifers monitored by the network in the western part of the state are the Bear Butte Creek, Cheyenne River, Rapid Creek, and Spearfish Creek aquifers. The remaining aquifers monitored by the network are located in the eastern part of the state. These aquifers are composed primarily of outwash and contain varying amounts of alluvium.

DISCUSSION OF WATER QUALITY

Discussion by Constituents

Nitrate

Nitrate plus nitrite as nitrogen is referred to, in the rest of this report, as nitrate. Nitrate in ground water is of concern because of its potential health effects on human infants and on animals. The toxicity of nitrate to humans has been demonstrated by vasodilatory/cardiovascular effects at high dosage and methemoglobinemia at lower doses (Federal Register, 1985). An additional concern is that several studies indicate there are correlations between nitrate ingestion and cancer (Cantor, 1997). Ingestion by young and ruminant animals (cattle, sheep, etc.) of water containing 100 milligrams per liter (mg/L) or more of nitrate should be considered dangerous (Roberts, 1990). In addition, nitrate in high concentrations can be an indicator of human impact on ground water.

Nationwide, dissolved nitrogen in the form of nitrate is a common pollutant in ground water. Anthropogenic (related to human activity) sources of nitrate in ground water include septic tanks, animal feeding areas, “over fertilized” farm fields, and fertilizer spills. Principle natural sources of nitrate are soil, air, and nitrogen rich geologic units. Concentrations of nitrate above 3 mg/L may be indicative of human impact (Madison and Brunet, 1984). A baseline database established prior to the onset of widespread agricultural activities in South Dakotas is not available. A concentration of 3 mg/L is therefore used as an approximate threshold indicator of possible human impact throughout the remainder of this report.

The amount of nitrate that actually enters and persists in ground water is controlled by a complex set of processes (Madison and Brunett, 1984). Nitrogen may be assimilated by plants or microorganisms before even reaching the water table. Ammonification (conversion of nitrogen to ammonia) may occur as organic matter decomposes; or conversely, nitrification may take place wherein ammonia is oxidized to produce nitrate and/or nitrite. Denitrification is an important process occurring beneath the water table in oxygen deficient waters whereby nitrate is converted by reducing bacteria to nitrogen or nitrous oxide.

Movement of nitrate bearing water through the unsaturated zone to the water table is facilitated by coarse grained, hydraulically conductive soils. Other factors determining the extent to which water infiltrates through soils include the amount of precipitation and soil moisture. Movement of water within the zone of saturation is controlled by the hydraulic conductivity of the aquifer and the hydraulic gradient.

A summary of the nitrate data for the statewide ground water quality monitoring effort is listed in table 2. Where analyses did not detect nitrate, it was assumed that the nitrate concentration was half the concentration of the detection limit in effect for each analysis. This assumption was made to allow for the calculation of statistics for the data. Wells located at the same site are designated as such by lying within horizontal grid lines in table 2. At most monitoring sites there are two wells, although several monitoring sites consist of only one well. For monitoring sites consisting of two wells, the shallower well screened at or near the water table is listed first in table 2 and the deeper well is listed below the shallower well. Table 2 also indicates the aquifers monitored by the respective wells, the number of samples analyzed, and the minimum, median, and maximum nitrate concentration for each well.

Figure 3 summarizes the nitrate data for each monitoring site. The maximum concentrations for each monitoring site are depicted symbolically as falling within one of three ranges of nitrate concentrations. These ranges are 2.99 mg/L or less, 3.00 – 9.99 mg/L, and 10 mg/L and greater. In addition, the median nitrate concentration for both the relatively deep and shallow wells (where two wells are present) is indicated for each monitoring site. The South Dakota Drinking Water Standard of 10 mg/L for nitrate has been exceeded in samples from 24 sites monitoring glacial outwash aquifers located in the eastern part of the state. Glacial outwash aquifers from which samples contained nitrate in excess of 10 mg/L include the Antelope Valley, Big Sioux, Bowdle, Delmont, Missouri, Parker-Centerville, Skunk Creek, Tulare, Vermillion-East-Fork, and Vermillion-West-Fork aquifers. Samples from wells completed in the Ogallala aquifer, a bedrock aquifer in Tripp County, also had nitrate concentrations exceeding the drinking water standard. There were 10 monitoring sites where at least one well had a median concentration greater than

10 mg/L. Median nitrate concentrations in excess of 10 mg/L were determined for wells monitoring the Antelope Valley, Big Sioux, Bowdle, Delmont, Missouri, and Ogallala aquifers.

Nitrate concentrations exceeding 3 mg/L were found in 14 of the 18 aquifers for which data were available (fig. 3). The four aquifers that never had nitrate concentrations exceeding 3 mg/L were the Highmore-Blunt, Cheyenne River, Rapid Creek, and Selby.

The minimum, median, and maximum nitrate concentrations were generally highest for the shallower wells at each monitoring site, as indicated on figures 4 and 5 as well as on table 2. This distribution of nitrate concentrations is also depicted graphically on figure 6 which shows the nitrate concentration versus depth below the water table for all samples collected for this project from 1989 through 1997. Figure 6 shows that nitrate concentrations greater than 10 mg/L occur exclusively within 25 feet of the water table, and nitrate concentrations greater than about 25 mg/L only occur within 15 feet of the water table. Samples from the Ogallala aquifer with nitrate concentrations greater than 60 mg/L were all collected within 10 feet of the water table.

At four monitoring sites, a departure from the general pattern of higher nitrate concentrations occurring near the water table was noted. A good example of this was noted in wells R20-90-15 and R20-90-16, located in the Bowdle aquifer. The median nitrate concentration in the shallow well (R20-90-15) was 1.98 mg/L while a median concentration of 12.95 mg/L was observed in the deeper well (R20-90-16).

The nitrate concentration increased as the water table dropped (and decreased as the water table rose) in three wells. Two of these wells monitor the Big Sioux aquifer and one well monitors the Vermillion-West-Fork aquifer. The best example of this indirect correspondence between nitrate concentration and water table elevation, observed in well R20-88-01, is shown in figure 7. A direct correlation between depth to the water table and nitrate concentration (nitrate concentration rose with a rising water table and fell with a falling water table) was noted in data from six shallow wells. A good example of a direct correlation between nitrate concentration and depth to water table is observed in well R20-94-06, which is graphically depicted in figure 8. Nitrate concentrations in samples from other wells in the monitoring network did not show such a clear correlation with water table level.

In reviewing nitrate concentrations statewide, it was often noted that short-term fluctuations in nitrate substantially exceeded long term variation. This relationship was particularly evident in data from wells that have been monitored for a relatively long time and have been sampled on multiple occasions within the same year. Figure 9, which shows nitrate concentrations in well R20-89-42 over time, is a good example of this phenomenon. Nitrate concentrations throughout the monitoring network generally show only minimal long-term change.

There were a few cases, however, where the nitrate concentrations either rose or fell consistently over time. Nitrate concentrations have fallen in wells R20-94-12 and R20-89-10, which monitor ground water in the Big Sioux and Bowdle aquifers, respectively. Data from well R20-94-12 provide the best example of this drop, as they document nitrate concentrations falling from 47.2 mg/L in mid-1994 to 13.0 mg/L in 1997. From 1994 to 1997, the nitrate concentration measured in samples from well R20-89-10 fell from 16.5 mg/L to 2.0 mg/L. Well R20-94-09,

monitoring the Big Sioux aquifer, showed a small but consistent rise in nitrate concentrations from 19.3 mg/L in 1994 to 30.2 mg/L in 1997. From September 1994 through September 1997, the nitrate concentration in water monitored by well R20-90-10, located in the Parker-Centerville aquifer, rose steadily from 4.23 mg/L to 10.7 mg/L.

Rising nitrate concentrations were also documented in two wells monitoring the Ogallala aquifer. Nitrate concentrations monitored in well R20-94-39 rose from 0.66 mg/L in early 1995 to 28.2 mg/L in late 1997. In well R20-94-41, nitrate concentrations increased from 22.1 mg/L to 145 mg/L from early 1995 to late 1997.

Pesticides

Synthetic organic compounds used as pesticides over the last half century have helped increase crop yields by reducing the impact of pests such as insects, weeds, and fungi. The extent to which pesticides migrate from soil into ground water is dependent on several factors (McBride and others, 1988). Characteristics of the pesticide such as volatility and decomposition rate are two such factors. The amount of the pesticide applied also affects the potential for ground water contamination. Soil properties such as absorptive capacity and hydraulic conductivity may also be determining factors. The reaction of pesticides in soil with water may be hastened by the presence of microbes. Some pesticides, such as atrazine, react with water in soil to form new compounds (transformation products). A pesticide metabolite is a transformation product that is the product of the transformation of a pesticide by a plant or animal. Other physical or chemical processes may also produce pesticide transformation products.

Table 3 (modified from McBride and others, 1988) lists the pesticides monitored in the statewide ground water quality monitoring effort. The relative persistence and mobility in soils, expressed qualitatively, of most of these pesticides is also listed on table 3. As can be seen on this table, most pesticides in common use are either non-mobile or non-persistent and therefore should not pose a significant long term threat to ground water, especially if prudent agricultural practices are employed. Atrazine, picloram, and simazine, however, are compounds that may pose continual problems as a result of their persistence and mobility. Also included in table 3 are maximum contaminant levels established by the U.S. Environmental Protection Agency or lifetime health advisory levels for each pesticide, if established. In addition, the use of each pesticide is listed.

Appendix B lists all the pesticides and atrazine transformation products monitored since 1991 in the statewide ground water quality monitoring effort. It is organized by aquifer, with the number of analyses and detections for each pesticide indicated. At least one analysis was performed for 35 pesticides and 2 atrazine transformation products. A total of 16,532 analyses have been performed. Pesticides or atrazine transformation products were detected in 212 of these analyses for an overall detection rate of about 1 percent. There were 11 different pesticides and both of the atrazine transformation products detected at least once each. Atrazine or one of its transformation products was the most commonly detected pesticide. Figure 10 is a plot of the number of pesticide and atrazine transformation product analyses performed and the number of pesticide and atrazine transformation product detections occurring at each monitoring site in the

network. The total number of analyses and detections for just atrazine and atrazine transformation products occurring at each monitoring site are shown on figure 11.

Samples collected in 1996 and 1997 for the statewide ground water quality monitoring effort were analyzed at the South Dakota Department of Health Laboratory. The detection limits effective at this facility for many pesticides were higher than those in effect at the University of Iowa Health Laboratory, to which samples had previously been sent. In changing laboratories, the detection limit for bentazon, bromoxynil, 2-4-D, dicamba, and picloram increased by a factor of 10, from 0.2 micrograms per liter (ug/L) to 2.00 ug/L. For DCPA, the limit of detection changed from 0.05 to 0.500 ug/L. The detection limit for cyanazine increased from 0.1 to 1.00 ug/L. For desisopropyl atrazine, the change in detection limits was from 0.1 to 2.00 ug/L. The detection limit in effect for many other pesticides increased from 0.1 to 0.500 ug/L with the change in laboratories. The probability of detecting these pesticides in samples collected in 1996 and 1997 was therefore reduced. Therefore, much of the pesticide detection data from 1996 and 1997 cannot be directly compared to the same data generated for previous years, particularly in evaluating long-term trends.

MCPA is the only pesticide for which the detection limit was lowered when the South Dakota Department of Health Laboratory began performing analyses for the monitoring effort. Prior to 1996, the detection limit for MCPA was 200 ug/L whereas its maximum contaminant level is only 10 ug/L. The detection limit in effect at the South Dakota Department of Health Laboratory for analyses performed in 1996 and 1997 was 0.500 ug/L. As a result, concentrations of MCPA in excess of its maximum contaminant level in samples collected before 1996 from the statewide ground water quality monitoring network may have gone undetected.

The detection limits for alachlor, atrazine, metolachlor, simazine, and desethyl atrazine were the same for the two laboratories. These compounds are among the more frequently detected pesticides and pesticide transformation products. The data generated in 1996 and 1997 for these parameters can therefore be directly compared to the earlier data in assessing long-term trends.

There was at least one detection of a pesticide or transformation product from 17 of the 19 monitoring sites in the Big Sioux aquifer. Statewide, 166 of the 212 detections of pesticides and pesticide transformation products were from the Big Sioux aquifer. This proportion of detections at least partly reflects the fact that the Big Sioux is the only aquifer that has been monitored for pesticides and pesticide transformation products since 1991 and is currently monitored by the greatest number of wells.

There was at least one detection of a pesticide or a pesticide transformation product from all four monitoring sites in the Skunk Creek aquifer. In the Skunk Creek aquifer, 14 of the 21 detections were from wells R20-94-17 and 18, which are at the same monitoring site. All four detections from the Delmont aquifer and all three detections from the Parker-Centerville aquifer came from one site in each aquifer. Pesticides were detected once in the Tulare, Highmore-Blunt, and Vermillion-West-Fork aquifers.

There was at least one detection from the two monitoring sites in the Bear Butte Creek aquifer and from the two monitoring sites in the Spearfish Creek aquifer. There were seven

detections from the Bear Butte Creek aquifer and eight detections from the Spearfish aquifer. It is entirely possible that other aquifers in the state, from which few or no detections occurred, might have shown a similar number of detections had they been sampled as many times, from as many wells, and for the same years as the Big Sioux aquifer.

Atrazine or one of its transformation products, desethyl atrazine and desisopropyl atrazine, was detected at least once in 14 of the 19 monitoring sites in the Big Sioux aquifer. At least one of these three compounds was detected in three of the four sites monitoring the Skunk Creek aquifer. They accounted for 59 percent of the pesticide detections in the Big Sioux aquifer and 62 percent of the detections in the Skunk Creek aquifer. Atrazine or one of its transformation products was detected in one monitoring site from both the Highmore-Blunt and Delmont aquifers. They accounted for all of the detections in these aquifers.

In general, the transformation products of atrazine were detected in the same samples as atrazine. Most analyses of samples from wells R20-94-09 and R20-94-13, both of which monitor the Big Sioux Aquifer, that detected atrazine transformation products did not detect atrazine. Desethyl atrazine was the only pesticide or transformation product detected in the Delmont aquifer. These examples of the detection of transformation products where the parent compound is present at concentrations under its detection limit, or possibly not present at all, underscore the importance of testing for pesticide transformation products.

Other pesticides detected in the monitoring effort were alachlor, bentazon, cyanazine, DCPA, 2,4-D, dicamba, metolachlor, picloram, simazine, and trifluralin. All of these pesticides were detected in samples collected from the Big Sioux aquifer. Bentazon, DCPA, 2,4-D, dicamba, and trifluralin were detected only in samples from the Big Sioux aquifer. Alachlor, metolachlor, and simazine were detected in the Bear Butte Creek, Big Sioux, Parker-Centerville, Skunk Creek, and Spearfish Creek aquifers. Cyanazine was detected in samples from the Big Sioux, Bear Butte Creek, and Spearfish Creek aquifers. Picloram was detected in the Big Sioux, Tulare, and Vermillion-West-Fork aquifers.

A pesticide maximum contaminant level or lifetime health advisory adopted by the state of South Dakota was exceeded eight times. The highest concentrations detected for atrazine and cyanazine, 4.2 ug/L and 8.8 ug/L, respectively, were detected in the same sample collected on June 29, 1993, taken from well R20-89-54 which monitors the Big Sioux aquifer. The maximum contaminant level for atrazine and lifetime health advisory for cyanazine are 3.0 ug/L and 1.0 ug/L, respectively. Two other samples containing cyanazine in excess of its lifetime health advisory at 1.2 and 1.5 mg/L were also collected from well R20-89-54 during the summer of 1993. A concentration of cyanazine of 2.7 mg/L, which also exceeded the maximum contaminant level, was found in a sample collected on June 29, 1993, from well R20-89-55. Wells R20-89-54 and R20-89-55 comprise a single monitoring site. Cyanazine was also detected once above its lifetime health advisory of 1 ug/L at a concentration of 2.49 ug/L in another well monitoring the Big Sioux aquifer, R20-94-15. Cyanazine was also detected at concentrations above its lifetime health advisory in samples collected from the Bear Butte Creek and the Spearfish Creek aquifers, one time per aquifer. These concentrations were 1.04 and 2.05 ug/L, respectively, in samples collected from well R20-95-100 located in the Bear Butte Creek aquifer and well R20-95-102 located in the Spearfish Creek aquifer. Both samples were collected on June 11, 1996.

Pesticide detections were not uniformly dispersed within aquifers, such as the Big Sioux and Skunk Creek aquifers (fig. 10), for which there were multiple detections. Monitoring sites in these aquifers having relatively high rates of detection as compared to other monitored aquifers are interspersed with sites from which very few or no detections have been made. Inter-aquifer comparisons should be made tenuously as the number of analyses may vary from aquifer to aquifer by two or even three orders of magnitude. In addition, the detection limits for the pesticide analytical data for 1996 and 1997 differ from most previously generated pesticide data.

Some pesticides that were detected in the first few years of the statewide monitoring effort have not been detected in more recent years, while the detection frequency for other pesticides has recently increased. Trifluralin was detected only in 1991 and 1992. Dicamba appeared in detectable concentrations in samples only in 1993. The detection frequency for atrazine in samples from the Big Sioux aquifer peaked in 1993. By contrast, most detections of alachlor and metolachlor occurred in 1996 and 1997. Simazine was detected 10 times in samples collected in 1996 and 1997 whereas it was not detected at all in 1995, the only other year in which analyses for simazine were performed. Atrazine and bentazon are the only pesticides detected in all 7 years of sampling for the statewide ground water quality monitoring effort covered by this report. Tests for atrazine transformation products were not performed until 1993. Desethyl atrazine has been detected in all years in which analyses for desethyl atrazine were performed.

More pesticide species were detected in 1993 in samples collected from the Big Sioux aquifer than in any other year. Heavy rainfall and flooding occurred that year. The peak in the variety of pesticides detected in 1993 may have resulted from either the intense direct infiltration of precipitation through the soil profile or the recharge of ground water by pesticide laden stream water, or both.

There seems to be little, if any, correlation between the qualitative measures of persistence and mobility in soils of the various pesticides listed on table 3 and their frequency of detection. A thorough evaluation of the detection history of each site would involve identifying all the processes that influence the fate and transport of contaminants including local agricultural practices. Such a comprehensive evaluation is beyond the scope of this report.

General Chemistry

Common inorganic constituents of ground water were examined in samples collected on an annual basis as part of the statewide ground water quality monitoring effort. Parameters analyzed for were calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, total dissolved solids, electrical conductivity, iron, manganese, fluoride, hardness, pH, and alkalinity. Cyanide was sampled for once every 5 years at each monitoring site. The maximum and minimum concentrations as well as the number of samples of selected inorganic parameters are listed by aquifer on table 4.

The data collected for the statewide ground water quality monitoring effort indicate most ground water in the state to be slightly alkaline, with pH values ranging generally from about 7

to just over 8. With respect to common cations and anions, most samples collected exhibited calcium bicarbonate waters with total dissolved solids generally ranging from roughly 400 to 1,200 mg/L. The highest total dissolved solids concentrations, approximately 2,600 mg/L, were observed in samples from the Cheyenne River aquifer.

Secondary maximum contaminant levels are standards set by the federal government for constituents of drinking water in public water supplies that, in relatively high concentrations, constitute nuisances rather than health concerns. Concentrations exceeding the secondary maximum contaminant level for sulfate of 500 mg/L occurred in the Bear Butte Creek, Cheyenne River, Delmont, Highmore-Blunt, Parker-Centerville, Rapid Creek, Selby, Skunk Creek, Spearfish Creek, and Tulare aquifers. Detections above the secondary maximum contaminant level of 1,000 mg/L for total dissolved solids were common in samples from the four alluvial aquifers at the periphery of the Black Hills, especially the Cheyenne River aquifer. The secondary maximum contaminant level for total dissolved solids was also exceeded in the Skunk Creek, Parker-Centerville, Ogallala, Highmore-Blunt, Delmont, Selby, and Tulare aquifers. The secondary maximum contaminant levels of 250 mg/L for chloride, and less than 6.5 or greater than 8.5 for pH were not exceeded, although the maximum chloride concentration from the Tulare aquifer was 246 mg/L. Analyses for 106 samples from throughout the state have been performed for cyanide with no detections occurring.

Trace Metals

Sampling for trace metals as part of the statewide ground water quality monitoring effort commenced in 1994. Since then, 117 samples have been analyzed for a suite of metals consisting of arsenic, barium, beryllium, cadmium, chromium, copper, mercury, nickel, lead, antimony, selenium, and thallium. This list of metals was established in consultation with the Drinking Water Program of the South Dakota Department of Environment and Natural Resources. Wells comprising the statewide monitoring network are sampled once every 5 years. As a result of this sampling frequency, the Delmont and Vermillion-West-Fork aquifers had not been sampled for trace metals as of the end of sampling in 1997.

A maximum contaminant level for one of these metals was exceeded only once. Arsenic, at a concentration of 80 ug/L, was found in a sample from well R20-95-11, above its maximum contaminant level of 50 ug/L. Well R20-95-11 monitors water quality in the Missouri aquifer. There were 42 other samples which had detectable quantities of arsenic below the maximum contaminant level. In addition to the Missouri aquifer, arsenic was detected in the Antelope Valley, Bowdle, Highmore-Blunt, Ogallala, Parker-Centerville, Selby, Skunk Creek, Spearfish Creek, Tulare, and Vermillion-East-Fork aquifers. Barium was detected 91 times across the state in all aquifers for which it was sampled except the Highmore-Blunt and Bear Butte Creek aquifers. Mercury was detected only twice, once in the Spearfish Creek aquifer and once in the Cheyenne River aquifer. Lead was present 18 times at detectable concentrations from the Bear Butte Creek, Big Sioux, Cheyenne River, Highmore-Blunt, Missouri, Ogallala, Sand Hills, Selby, Spearfish Creek, and Vermillion-East-Fork aquifers. Cadmium was detected three times in the Big Sioux aquifer. Cadmium was also detected in the Selby, Cheyenne River, and Spearfish Creek, one time per aquifer.

Chromium and nickel were identified in 36 and 47 samples, respectively. While they were both detected in most aquifers, neither chromium nor nickel were detected in the Big Sioux, Rapid Creek, Sand Hills, or Skunk Creek aquifers. In addition, chromium was never detected in the Antelope Valley or Bear Butte Creek aquifers, nor was nickel ever detected in the Ogallala aquifer. Antimony was detected 24 times with detections occurring in the Bowdle, Highmore-Blunt, Missouri, Parker-Centerville, Selby, Tulare, and Vermillion-East-Fork aquifers. Detectable levels of copper were found four times in the Ogallala aquifer, three times in the Big Sioux aquifer, three times in the Missouri aquifer, and once in the Spearfish Creek aquifer. Thallium was detected twice, once in the Spearfish Creek aquifer and once in the Tulare aquifer. Selenium was detected 36 times. Selenium was never detected in samples from the Skunk Creek, Sand Hills, Ogallala, and Spearfish Creek aquifers.

Volatile Organic Compounds

Since 1994, a total of 30 samples have been analyzed for a suite of 22 volatile organic compounds (table 5). A sampling frequency for volatile organic compounds of one time per 5 years in 25 percent of an aquifer's monitoring sites has been established for the monitoring sites comprising the statewide ground water monitoring network. At least one sample from each aquifer was analyzed for volatile organic compounds except in the Delmont and Sand Hills aquifers. There were no scheduled sampling events for any of the monitoring sites in these two aquifers during or before 1997. Xylene was detected once at a concentration of 0.9 mg/L in a sample collected from well R20-89-48, located in the Big Sioux aquifer. There were no other detections of volatile organic compounds.

Radionuclides

From 1994 through 1997, 117 samples have been analyzed for gross alpha emitters. Monitoring sites were sampled for radionuclides at a frequency of one time per 5 years. At least one sample from each aquifer was analyzed for gross alpha emitters during this time except the Delmont and Vermillion-West-Fork aquifers. The sampling schedule did not include sampling of any of the monitoring sites in either of these two aquifers during or prior to 1997. Gross alpha emitters were reported at 22.0 ± 3.1 picocuries per liter (pCi/L) in a sample from well R20-94-33, located in the Ogallala aquifer. This analysis documented the only instance where the gross alpha value exceeded the maximum contaminant level of 15 pCi/L. A sample from well R20-94-21, located in the Skunk Creek aquifer, reportedly emitted gross alpha particles at 13.8 ± 2.2 pCi/L. Due to the reporting range of concentrations, this sample may have emitted gross alpha particles in excess of the maximum contaminant level as well. Because of its gross alpha emission rate greater than 15 pCi/L, the sample from well R20-94-33 was also analyzed for uranium. The uranium concentration in this sample was found to be 17.9 ± 1.9 ug/L uranium, just under the uranium maximum contaminant level of 20 ug/L. No other samples have been tested for uranium as of the end of sampling in 1997.

There were 56 samples analyzed for gross alpha emitters that were also tested for radium 226 plus radium 228. Samples collected from 1994 through 1996 with gross alpha emission rate range midpoints of 2.0 pCi/L were generally analyzed for radium 226 plus radium 228. Samples collected in 1997 were analyzed for radium 226 plus radium 228 if their reported gross alpha emission rate range midpoints exceeded 5 pCi/L. The concentration of 5 pCi/L is also the same as the maximum contaminant level for radium 226 plus radium 228. The radium 226 plus radium 228 maximum contaminant level may have been exceeded in samples taken from wells R20-95-09, R20-95-97, R20-95-102, and R20-95-104, once per well. The uncertainty as to whether these samples actually exceeded the radium 226 plus radium 228 maximum contaminant level arises from the reporting of their emission rates as a range of values. The first two of these wells monitor ground water quality in the Missouri and Bear Butte Creek aquifers, respectively, while the latter two wells are screened in the Spearfish Creek aquifer.

Discussion by Aquifer

Antelope Valley Aquifer

The Antelope Valley aquifer is an elongate aquifer trending northwest-southeast for about 25 miles through portions of Grant, Codington, and Deuel Counties. Two monitoring sites consisting of two nested wells at each site have been established to monitor this aquifer (fig. 1). The median and maximum nitrate concentrations from shallow wells at both monitoring sites are above the maximum contaminant level of 10 mg/L, suggesting impact from human activity (fig. 3; table 2). Apart from elevated nitrate levels, the quality of ground water from this aquifer is quite good, as its dominant inorganic constituents in water monitored are calcium and bicarbonate. Total dissolved solids concentrations are typically about 400 mg/L. Out of 152 analyses in 8 samples for various pesticides and atrazine transformation products, there have been no detections (app. B).

Bear Butte Creek Aquifer

The Bear Butte Creek aquifer is located northeast of Sturgis and southeast of Bear Butte beneath and adjacent to Bear Butte Creek. Two monitoring sites consisting of one water quality monitoring well per site are present in this aquifer (fig. 1). The median and maximum nitrate concentrations from both wells monitoring this aquifer are above 3 mg/L (fig. 3; table 2), possibly indicating contamination from human activities.

From seven samples tested for various pesticides and atrazine transformation products from the Bear Butte Creek aquifer (app. B; figs. 10 and 11), there were seven detections. Cyanazine, the sole pesticide detected in this aquifer above a maximum contaminant level or a lifetime health advisory, was detected at a concentration of 1.04 ug/L in a sample collected in 1996. The lifetime health advisory for cyanazine is 1.0 ug/L. The sample came from well R20-95-100, the northeasternmost of the two wells currently monitoring the aquifer. In addition there were two detections of alachlor, two detections of metolachlor, and one detection of simazine from this well. There was one detection of simazine from well R20-95-97. Simazine was the only pesticide

detected in this well. These detections of pesticides are indicative of human impact to the Bear Butte Creek aquifer.

The radium 226 plus radium 228 maximum contaminant level of 5 pCi/L was exceeded in the same sample that contained cyanazine above its lifetime health advisory. Calcium and sodium are the dominant cations in the water sampled from the Bear Butte Creek aquifer. Sulfate and bicarbonate, the dominant anions in the Bear Butte Creek aquifer, have been measured in nearly equal amounts in some samples with sulfate dominant in others. Total dissolved solids concentrations ranged from about 850 to 2,200 mg/L.

Big Sioux Aquifer

The Big Sioux aquifer is a large and important glacial outwash aquifer in South Dakota. It occupies the subsurface below and adjacent to the Big Sioux River and its tributaries from northwestern Grant County to the southeast tip of the state. The monitoring network in the Big Sioux aquifer consists of 19 monitoring sites, as can be seen on figure 1. All but two of these sites consist of two nested water quality monitoring wells.

Maximum concentrations of nitrate exceeded the nitrate maximum contaminant level of 10 mg/L at 10 of the 19 Big Sioux aquifer monitoring sites (fig. 3; table 2). Only three monitoring sites yielded maximum nitrate concentrations of less than 3 mg/L. In addition, median nitrate concentrations from shallow wells at 12 of the 19 well sites monitoring this aquifer were in excess of 3 mg/L. These observations are strongly suggestive of the impact of agricultural or other human activities upon water in the Big Sioux aquifer.

The southern portion of the aquifer appears particularly impacted with nitrate (fig. 3). Maximum nitrate concentrations greater than 10 mg/L and median nitrate concentrations above 3 mg/L were determined for the southernmost four well sites in the aquifer. Elsewhere within the aquifer, monitoring sites from which data suggest minor human impact are interspersed with monitoring sites where there has apparently been greater impact.

The data from wells R20-94-09 and R20-94-12 indicate rising and falling nitrate concentrations, respectively. However, as discussed elsewhere in this report, data from most wells do not indicate consistently rising or falling nitrate concentrations. It is inferred, therefore, that any general increase in nitrate concentrations resulting from human activities in the Big Sioux aquifer above ambient concentrations occurred prior to the implementation of the statewide ground water quality monitoring effort. It appears that nitrate concentrations are currently subject to much greater short term fluctuation than long term change as exemplified in figure 9.

A total of 9,679 analyses for various pesticides and atrazine transformation products were conducted on 473 samples taken from the Big Sioux aquifer from 1991 through 1997 (app. B; figs. 10 and 11). There were 166 of these analyses that resulted in detections. As discussed earlier, atrazine and two of its transformation products account for 59 percent of these detections. Atrazine, desethyl atrazine, and desisopropyl atrazine were detected 69, 20, and 9 times,

respectively. Atrazine transformation products were detected in greater concentrations than atrazine in eight samples from the Big Sioux aquifer. Cyanazine was identified 15 times while bentazon was determined to be present in 11 samples. Other pesticides detected in samples taken from the Big Sioux aquifer were alachlor, 2,4-D, DCPA, dicamba, metolachlor, picloram, and trifluralin. While DCPA was detected infrequently, it was also analyzed for much less often than most other detected pesticides.

In contrast to the nitrate data, the distribution of pesticide detections suggests the southernmost one-third of the Big Sioux aquifer to be much less impacted by human activity than the rest of the aquifer. Of all detections of pesticides and atrazine transformation products from the Big Sioux aquifer, 66 percent have come from just three monitoring sites, R20-89-54 and 55, R20-89-49 and 50, and R20-94-12, with R20-94-12 having the highest rate of detection of pesticides. The only monitoring site in the aquifer, and the state, from which DCPA and dicamba were detected was R20-89-54 and 55. The only detection of atrazine above its maximum contaminant level of 3 ug/L to occur in the history of the statewide ground water quality monitoring effort, and four detections of cyanazine above its lifetime health advisory of 1.0 ug/L, were also from this monitoring site. Cyanazine was also detected above its lifetime health advisory in well R20-94-15. Detected pesticide concentrations and species are not uniformly distributed throughout the Big Sioux aquifer. The greatest impact from pesticides occurs in Minnehaha, Moody, and Hamlin Counties (fig. 10).

Only atrazine and bentazon were detected in all years from 1991 through 1997. Dicamba has not been detected since 1993. Picloram and trifluralin were last detected in 1992. Alachlor and metolachlor were detected more frequently in 1996 and 1997 than in previous years. Simazine was not detected at all until 1996.

The data generated indicate good general water quality within the Big Sioux aquifer, not accounting for nitrate and pesticides. Calcium is the dominant cation in samples collected from the Big Sioux aquifer. Bicarbonate is generally the dominant anion although sulfate is occasionally the dominant anion. Total dissolved solids concentrations range from about 200 to 1,000 mg/L.

Bowdle Aquifer

The Bowdle aquifer is an irregularly shaped aquifer that generally trends north-south. It is located in portions of Edmunds, Walworth, and Potter Counties. There are five monitoring sites in the Bowdle aquifer (fig. 1). All but one of these sites consists of two nested water quality monitoring wells. Nitrate data from the Bowdle aquifer suggest impact from human activity (fig. 3; table 2). Well R20-90-15, in particular, appears to show human impact on this aquifer, having a maximum nitrate concentration of 29.80 mg/L and a median nitrate concentration of 13.0 mg/L. Maximum and median concentrations for other shallow wells monitoring the Bowdle aquifer are usually above 3.0 mg/L, further suggesting human impact (fig. 3; table 2).

Pesticide analytical data from the Bowdle aquifer do not indicate contamination, as there have been no detections out of the 1,208 analyses for various pesticides and atrazine

transformation products from 73 samples (app. B; figs. 10 and 11). The dominant cation in water from the Bowdle aquifer is usually calcium but is occasionally sodium. The samples collected contain bicarbonate as the dominant anion. Total dissolved solids concentrations range from about 300 to 950 mg/L.

Cheyenne River Aquifer

The monitored portion of the Cheyenne River aquifer is located beneath and adjacent to the northeast flowing portion of the Cheyenne River east of the town of Hot Springs. Single water quality monitoring wells located at two monitoring sites make up the monitoring network in the Cheyenne River aquifer (fig. 1). Nitrate concentrations in the four samples collected from this aquifer are not suggestive of human impact (fig. 3; table 2). Of the 60 analyses performed for various pesticides and atrazine transformation products from four samples collected in this aquifer, there have been no detections (app. B; figs. 10 and 11). The water quality of the aquifer is poor in regard to common inorganic constituents, however, with the dominant cation sodium averaging almost 500 mg/L and concentrations of sulfate, the dominant anion, consistently exceeding 1,000 mg/L. The total dissolved solids concentrations average about 2,600 mg/L.

Delmont Aquifer

The Delmont aquifer lies beneath and adjacent to Choteau Creek for about 25 miles in Charles Mix and Douglas Counties. There are two monitoring sites consisting of two nested wells per site in the Delmont aquifer as part of the monitoring network (fig. 1). The shallow wells at the two monitoring sites that monitor the Delmont aquifer show indications of human impact (fig. 3; table 2). Median nitrate concentrations from these shallow wells are 9.5 and 33.3 mg/L. There were four detections of desethyl atrazine from samples collected from well R20-91-55 (app B; figs. 10 and 11). Out of the 365 analyses of 22 samples from the Delmont aquifer analyzed for various pesticides and atrazine transformation products, these were the only detections (fig. 10).

While calcium is the dominant cation in samples from the Delmont aquifer, magnesium rather than sodium is the secondary cation. Sulfate and bicarbonate alternate as the dominant anions in these samples. Total dissolved solids concentrations range from about 750 to 1,150 mg/L.

Highmore-Blunt Aquifer

The Highmore-Blunt aquifer trends east-west for about 30 miles in portions of Hyde, Sully, and Hughes Counties. There are five water quality monitoring wells located at three monitoring sites in the Highmore-Blunt aquifer (fig. 1). The nitrate data from the Highmore-Blunt aquifer do not suggest human impact (fig. 3; table 2). However, only one sample has been taken from each of the five wells that monitor this aquifer. There have been 63 analyses of five samples from the Highmore-Blunt aquifer for various pesticides and atrazine transformation products, resulting in

one detection (app. B; figs. 10 and 11). The detected pesticide was atrazine. The dominant cations and anions in water sampled from this aquifer are usually calcium and bicarbonate. Total dissolved solids concentrations range from about 250 to 1,700 mg/L.

Missouri Aquifer

The monitored portion of the Missouri aquifer is located beneath and adjacent to the Missouri River between Yankton, South Dakota, and Sioux City, Iowa. There are five monitoring sites consisting of two nested water quality monitoring wells per site in this aquifer (fig. 1). The limited amount of data collected through 1997 for the Missouri aquifer is generally not indicative of widespread nitrate contamination (fig. 3; table 2). Well R20-95-14, however, has yielded samples with a median nitrate concentration of 36.9 mg/L. There were 332 analyses of 20 samples for various pesticides and atrazine transformation products with no detections occurring (app. B; figs. 10 and 11).

The arsenic maximum contaminant level of 50 ug/L was exceeded in a sample from well R20-95-11. Well R20-95-09 yielded a sample containing radium 226 plus radium 228 at a concentration of 6.0 ± 1.9 pCi/L, which may have exceeded the maximum contaminant level for radium 226 plus radium 228 of 5 pCi/L. The uncertainty as to whether the maximum contaminant level was actually exceeded is due to the reporting of a range of emission rates. The water sampled from the Missouri aquifer generally was of good quality. Calcium is the dominant cation and bicarbonate is the dominant anion. Total dissolved solids range from about 200 to 1,000 mg/L.

Ogallala Aquifer

Unlike most monitored surficial aquifers in the state, the Ogallala aquifer covers a broad rather than elongate or sinuous surface pattern. This difference reflects the fact that the Ogallala aquifer is coincidental with the Ogallala Group, a bedrock geologic unit that covers large portions of Bennett, Tripp, Gregory, and Todd Counties. There are seven monitoring sites in the Ogallala aquifer (fig. 1). All but one of these monitoring sites consist of two nested water quality monitoring wells.

Nitrate data from shallow wells in southern Tripp County indicate rising nitrate concentrations, especially from well R20-94-41 where nitrate concentrations have risen from 22.10 mg/L in 1995 to 145 mg/L in 1997 (fig. 3; table 2). There have been no detections out of 1,088 analyses of 75 samples for various pesticides and atrazine transformation products taken from the Ogallala aquifer (fig. 3; table 2). The gross alpha maximum contaminant level of 15 pCi/L was exceeded in one sample from well R20-94-33. Calcium is generally the prevalent cation although some samples taken from this aquifer are high in sodium content. Bicarbonate is generally the dominant anion. Total dissolved solids concentrations usually range from 150 to 400 mg/L, but are occasionally as high as 1,300 mg/L.

Parker-Centerville Aquifer

The Parker-Centerville aquifer is located in Turner, Lincoln, and Clay Counties, adjacent to and beneath the Vermillion River. There are four monitoring sites consisting of two nested water quality monitoring wells per site in this aquifer (fig. 1). Three of the four shallow wells monitoring this aquifer have yielded samples containing nitrate concentrations suggestive of human impact to the aquifer (fig. 3; table 2). There have been three pesticide detections out of 1,446 analyses of 70 samples for various pesticides and atrazine transformation products. Alachlor, metolachlor, and simazine were detected once each in a sample taken from well CO-83-158 in 1997 (app. B; figs. 10 and 11). Water sampled from the Parker-Centerville aquifer typically has calcium as its dominant cation, with sulfate and bicarbonate being the main anions. The total dissolved solids concentrations in water sampled from the Parker-Centerville aquifer range from about 550 mg/L to 1,050 mg/L.

Rapid Creek Aquifer

The Rapid Creek aquifer is located beneath and adjacent to Rapid Creek for a 30-mile stretch east of Rapid City. There are two monitoring sites consisting of one water quality monitoring well per site in this aquifer (fig. 1). Like the Cheyenne River aquifer, the four samples collected from the Rapid Creek aquifer have not documented nitrate concentrations suggestive of human impact (fig. 3; table 2). In addition, there have been no detections of pesticides from the Rapid Creek aquifer in 111 analyses of 7 samples for various pesticides and atrazine transformation products (app. B; figs. 10 and 11). The water sampled from this aquifer has calcium as its dominant cation. Sulfate and bicarbonate are the dominant anions, occurring in approximately equal concentrations. Total dissolved solids concentrations in water sampled from this aquifer range from about 900 to 1,200 mg/L.

Sand Hills Aquifer

The Sand Hills aquifer directly overlies the Ogallala aquifer and consists of reworked Ogallala Group sand. Additional geologic mapping is needed to define the Sand Hills aquifer in South Dakota. Only one monitoring site consisting of two nested water quality monitoring wells has been developed in the Sand Hills aquifer as part of the statewide ground water quality monitoring effort (fig. 1). Of the eight samples collected from the Sand Hills aquifer, one nitrate concentration of 3.25 mg/L may be indicative of human impact (fig. 3; table 2). There have been no pesticides detected in 84 analyses of 6 samples for various pesticides and atrazine transformation products (app. B; figs. 10 and 11). The cations of calcium and sodium are present in water sampled from the Sand Hills aquifer in roughly equivalent amounts. Bicarbonate is generally the dominant anion. Total dissolved solids concentrations are very low, ranging from about 100 to 350 mg/L.

Selby Aquifer

The Selby aquifer is located primarily in Campbell County, but also is located in portions of Walworth and McPherson Counties. Two monitoring sites consisting of two nested water quality monitoring wells per site have been established to monitor water quality in this aquifer (fig. 1). Judging by the 46 analyses for various pesticides and atrazine transformation products in four samples collected from the Selby aquifer in 1996 and 1997, it does not appear that there has been human impact to this aquifer. No pesticides or atrazine transformation products were detected. The dominant cation in water samples from the Selby aquifer was calcium. Bicarbonate was generally the dominant anion. Total dissolved solids concentrations generally range from about 350 to 550 mg/L, although a concentration of 1,785 mg/L was identified in a sample that contained sulfate as its dominant anion.

Skunk Creek Aquifer

The Skunk Creek aquifer is located beneath and adjacent to Skunk Creek in Lake, Minnehaha, and Moody Counties. Four monitoring sites have been established in the Skunk Creek aquifer to monitor ground water quality (fig. 1). There are two nested water quality monitoring wells at each site. Maximum and median nitrate concentrations from well R20-94-18 of 10.90 and 3.8 mg/L, respectively, and from well R20-94-27 of 4.45 and 3.5 mg/L, respectively, are suggestive of human impact (fig. 3; table 2).

The 21 detections of various pesticides and atrazine transformation products out of 1,154 analyses of 54 samples collected in 1995, 1996, and 1997 from the Skunk Creek aquifer also indicate human impact. Most of these detections occurred in 1996 and 1997. The pesticides and atrazine transformation products detected in the Skunk Creek aquifer include alachlor, atrazine, desethyl atrazine, metolachlor, and simazine (app. B; figs. 10 and 11). Analyses of samples collected from monitoring wells R20-94-17 and 18 resulted in 14 of these detections.

Water samples taken from the Skunk Creek aquifer have calcium as their dominant cation. Sulfate and bicarbonate are the dominant anions. Total dissolved solids concentrations range from about 350 to 1,450 mg/L.

Spearfish Creek Aquifer

The Spearfish Creek aquifer is located beneath and adjacent to a short stretch of Spearfish Creek north of the town of Spearfish. Two monitoring sites have been established in this aquifer. One of these sites consists of two nested water quality monitoring wells while the other has only one well. The median nitrate concentrations from wells in the Spearfish Creek aquifer are generally not suggestive of widespread human impact; however, one sample from well R20-95-102 contained 5.4 mg/L of nitrate (fig. 3; table 2).

There were 228 analyses of 15 samples for various pesticides and atrazine transformation products. Cyanazine was detected above its lifetime health advisory of 1.0 mg/L at 2.05 mg/L in

well R20-95-102. Alachlor and metolachlor were also detected in samples from this well. Alachlor, atrazine, metolachlor, and simazine were detected one time each from well R20-95-103 (app. B; figs. 10 and 11). These detections are suggestive of impact from human activities.

The radium 226 plus radium 228 maximum contaminant level of 5 pCi/L may have been exceeded in a sample from well R20-95-102 and in a sample from well R20-95-104, which monitor the Spearfish Creek aquifer. The radium 226 plus radium 228 emission rates in these samples were 4.2 ± 1.4 pCi/L and 5.3 ± 1.9 pCi/L, respectively. The reporting of these radium 226 plus radium 228 emission rate ranges results in uncertainty as to whether the concentrations in these samples actually exceeded the maximum contaminant level. Calcium is typically the dominant cation, with sulfate and bicarbonate being the dominant anions. Total dissolved solids concentrations measured from the Spearfish Creek aquifer range from about 350 to 1,950 mg/L.

Tulare Aquifer

The monitored portion of the Tulare aquifer is located in Spink and Beadle Counties beneath and adjacent to the James River. There are two monitoring sites consisting of two nested ground water quality monitoring wells and one site which consists of only one well in the Tulare aquifer as part of the statewide ground water quality monitoring network (fig. 1). In the single sampling event conducted in the Tulare aquifer, samples collected from shallow wells were found to contain nitrate concentrations as high as 26.6 mg/L, suggesting human impact (fig. 3; table 2). Picloram was the only pesticide detected from the 84 analyses performed on five samples for various pesticides and atrazine transformation products in 1997. It was detected once (app. B; figs. 10 and 11). Calcium is the dominant cation in water sampled from the Tulare aquifer although calcium and sodium are occasionally present in almost equal amounts. Sulfate and bicarbonate are the dominant anions. Total dissolved solids concentrations from the Tulare aquifer range from about 450 to 2,100 mg/L.

Vermillion-East-Fork Aquifer

The Vermillion-East-Fork aquifer lies beneath and adjacent to the East Fork of the Vermillion River from Clark County to Turner County. Two monitoring sites consisting of two nested water quality monitoring wells per site have been established in this aquifer as part of the monitoring network (fig. 1). In the single sampling event conducted in this aquifer, an analysis from one of the shallow wells showed a nitrate concentration of 18.1 mg/L, suggesting human impact (fig. 3; table 2). As with other aquifers for which data are sparse, additional sampling will be needed to more confidently determine the extent and degree of human impact. Water from the Vermillion-East-Fork aquifer has been sampled four times. There were 70 analyses performed on these four samples for various pesticides and atrazine transformation products with no detections (app. B; figs. 10 and 11). The water quality of samples collected from the Vermillion-East-Fork aquifer, apart from nitrate, is generally good, with calcium and bicarbonate being the dominant cations and anions, respectively. Total dissolved solids concentrations range from about 350 to 700 mg/L.

Vermillion-West-Fork Aquifer

The Vermillion-West-Fork aquifer is located in McCook and Turner Counties beneath and adjacent to the West Fork of the Vermillion River. Data from this aquifer have been collected from a single monitoring site consisting of two nested water quality monitoring wells (fig. 1). Median nitrate concentrations of 8.6 and 5.1 mg/L from the two wells monitoring this aquifer are suggestive of human impact to ground water (fig. 3; table 2). There was one detection of picloram out of 260 analyses of 14 samples for various pesticides and atrazine transformation products (app. B; figs. 10 and 11). No other pesticides or transformation products have been detected. Calcium has been the dominant cation in samples collected from this aquifer. The most prevalent anions are sulfate and bicarbonate, which have been detected in nearly equal amounts. Total dissolved solids concentrations range from about 600 to 800 mg/L.

Additional Aquifers to be Monitored

Wells for monitoring ground water in the Arikaree, Coteau Lakes, Elm, and Spring Creek aquifers (fig. 1) were installed and developed in 1997 but were not sampled in 1997. As a result, ground water quality data from these wells have not been generated for this report.

SUMMARY AND CONCLUSIONS

By the end of 1997, a network of ground water quality monitoring wells consisting of 124 wells at 68 monitoring sites in 18 shallow aquifers throughout the state of South Dakota had been established. The analytical results of sampling of these monitoring sites, each of which were sampled at least once from 1989 to 1997, are the focus of this report. The network is designed to examine non-point sources of pollution and ambient water quality of sensitive surficial aquifers. At the present time, there are 145 wells at 80 monitoring sites in 25 aquifers comprising the statewide ground water quality monitoring network. Subsequent reports will include data and interpretations from the entire monitoring network.

The goal of the monitoring effort is to regularly and systematically assess the present ground water quality, the impact of agricultural chemicals on ground water, and long-term trends in water quality in sensitive aquifers. Most of the monitoring sites consist of a well that monitors the water table and a well that monitors water at a slightly greater depth. Some monitoring sites are comprised of a water table well only.

The drinking water quality standard, or maximum contaminant level, established by the state of South Dakota for nitrate is 10 mg/L. Most of the glacial outwash aquifers located in the eastern part of the state and the Ogallala aquifer, located in western South Dakota, yielded at least one sample containing nitrate in excess of its maximum contaminant level. Median nitrate concentrations in excess of 10 mg/L were determined for 10 of the monitoring sites, including

sites in the Antelope Valley, Big Sioux, Bowdle, Delmont, Missouri, and Ogallala aquifers (fig. 1).

Since pre-agricultural era baseline nitrate data are lacking, nitrate concentrations of 3 mg/L or greater are generally considered in this report to be suggestive of impact to ground water from human activities. The data suggest nitrate contamination from non-point sources to be common, particularly in the eastern part of the state. Maximum nitrate concentrations detected from at least one well at 45 of the 68 monitored sites equaled or exceeded the 3 mg/L nitrate concentration. Nitrate concentrations greater than 3 mg/L occurred in 14 aquifers (fig. 3; table 2). The only aquifers that did not yield at least one sample in excess of 3 mg/L were the Cheyenne River, Highmore-Blunt, Rapid Creek, and Selby. Median nitrate concentrations from at least one well at 30 monitoring sites exceeded 3 mg/L. Median nitrate concentrations were less than 3 mg/L for all wells in only the Cheyenne River, Rapid Creek, Spearfish Creek, and Sand Hills aquifers (fig. 3; table 2).

Short term fluctuations in nitrate levels were observed to usually exceed long term trends in shallow wells monitoring the Big Sioux aquifer. This relationship was evident in data from wells from which samples have been collected several times per year. In addition, nitrate concentrations in samples collected from most of these shallow wells were commonly greater than 3 mg/L. It, therefore, appears that the Big Sioux aquifer was impacted with nitrate pollution prior to implementation of the statewide ground water quality monitoring network.

Consistently rising levels of nitrate to 145 mg/L were observed in samples from a well monitoring the Ogallala aquifer. Additional study will be necessary to determine the source of the nitrate.

From a quantitative standpoint, pesticide pollution of ground water supplies in South Dakota does not appear to be a widespread problem. A total of 16,532 analyses for pesticides and atrazine transformation products in 866 samples were performed for the statewide ground water quality monitoring effort from 1991 through 1997. Only 212 of these analyses resulted in detections for an overall detection rate of about 1 percent. However, there have been notable rates of detection of pesticides and atrazine transformation products at several monitoring sites. Three monitoring sites in the Big Sioux aquifer and one site in the Skunk Creek aquifer have yielded samples containing detectable quantities of pesticides much more frequently than other monitoring sites in their respective aquifers. All four detections of desethyl atrazine from the Delmont aquifer came from one monitoring site. All of these monitoring sites are interspersed with monitoring sites from which relatively few, if any, pesticides have been detected.

Pesticides were also detected at anomalously high rates in two of the aquifers in the vicinity of the Black Hills. One well monitoring ground water in the Bear Butte Creek aquifer yielded samples containing detectable quantities of pesticides at a frequency of 11 percent. Pesticides were detected four times in samples from two of the three wells monitoring the Spearfish Creek aquifer.

About 59 percent of the analyses and 78 percent of the 212 detections of pesticides and atrazine transformation products were from samples collected from the Big Sioux aquifer.

Atrazine, desethyl atrazine, and desisopropyl atrazine accounted for 98 of the 166 pesticide and atrazine transformation product detections from the Big Sioux aquifer. Other pesticides detected in ground water sampled from the Big Sioux aquifer were alachlor, bentazon, cyanazine, DCPA, dicamba, 2,4-D, metolachlor, picloram, simazine, and trifluralin.

There was at least one detection of a pesticide or atrazine transformation product from eight aquifers other than the Big Sioux. There were 21 detections of pesticides, including alachlor, atrazine, desethyl atrazine, metolachlor, and simazine from wells monitoring the Skunk Creek aquifer. Alachlor, cyanazine, metolachlor, and simazine were all detected in samples from both the Bear Butte Creek and Spearfish Creek aquifers. Atrazine was also detected in one of the samples taken from the Spearfish Creek aquifer. Alachlor, metolachlor, and simazine were all detected once each in the Parker-Centerville aquifer. Picloram was detected once in the Tulare aquifer and one time from the Vermillion-West Fork aquifer. Desethyl atrazine was identified four times in samples collected from the Delmont aquifer. Atrazine accounted for the sole pesticide detection from the Highmore-Blunt aquifer.

There have been eight detections of a pesticide in excess of a maximum contaminant level established by the state of South Dakota or a lifetime health advisory. The lifetime health advisory of 1 ug/L for cyanazine was exceeded in seven analyses, five of which were in samples taken from the Big Sioux aquifer. The other two samples which contained cyanazine in excess of its lifetime health advisory were collected from the Bear Butte Creek and Spearfish Creek aquifers. One sample collected in the Big Sioux aquifer contained a concentration of 4.2 ug/L atrazine, exceeding the atrazine maximum contaminant level of 3 ug/L.

Samples analyzed in 1996 and 1997 were generally subject to higher detection limits for most pesticides than samples collected in previous years. This difference in detection limits precludes any direct comparison of the more recent pesticide data to the older pesticide data. Pesticides and atrazine transformation products for which the detection limits were the same for all years reported on herein were alachlor, atrazine, desethyl atrazine, metolachlor, and simazine. These five compounds were among the most frequently detected pesticides and atrazine transformation products analyzed for in the statewide ground water quality monitoring effort.

While most of the detections of atrazine transformation products occurred where atrazine was also present, the atrazine transformation products were detected in several samples that did not contain a detectable amount of atrazine. In fact, desethyl atrazine was detected four times in samples from the Delmont aquifer that did not contain detectable amounts of atrazine, underscoring the importance of testing for transformation products. The list of pesticide transformation products to be analyzed for in the future should be expanded to include compounds that are likely to persist in South Dakota's shallow aquifers and that are of concern on the basis of their toxicology. Consideration should be given to analyzing for transformation products of pesticides that have been detected infrequently or not at all, as well as transformation products of pesticides that have been detected more often.

The marked increase in the detection rates of alachlor, metolachlor, and simazine in 1996 and 1997 from earlier years exemplifies how the detection rate for pesticide species can suddenly change. The changes in the detection rates of these pesticides are an indication that continued

monitoring for most, if not all, pesticides monitored for in past years is warranted. Detections of atrazine, simazine, and picloram are of interest because of their tendency to persist in the soil profile, allowing them time to migrate to the water table. Continued monitoring of cyanazine would be prudent. Although its production for domestic use ceased in 1997, cyanazine was detected seven times in concentrations above its lifetime health advisory.

Most ground water samples collected were determined to be slightly alkaline, calcium bicarbonate waters. There were occasional exceptions, most notably water collected from the aquifers in the vicinity of the Black Hills, which were often high in sodium and sulfate. Total dissolved solids concentrations were generally less than 1,000 mg/L in the bedrock and glacial outwash aquifers. The ground water in the aquifers near the Black Hills, however, typically had total dissolved solids concentrations from about 1,000 to 2,600 mg/L. The data from the statewide ground water quality monitoring network showed that cyanide, trace metals, volatile organic compounds, and radionuclides do not pose a significant threat to ground water quality at this time.

Concentrations of nitrate greater than 3 mg/L occurred in several shallow aquifers in South Dakota, particularly in the eastern part of the state. Some aquifers showed nitrate concentrations above drinking water standards. Pesticide contamination does not appear to be widespread, although pesticides were consistently detected at several monitoring sites. Further assessment of the water in the state's shallow aquifers is warranted. This effort should include continued monitoring of existing wells and an ongoing evaluation of the parameters currently being analyzed. In addition, new monitoring sites could be developed to further evaluate areas where pollution is suspected on the basis of previous monitoring.

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Table 1. Monitoring well locations and depths

Aquifer and well name	Other well name	Well location	Well depth from casing top (ft)
Antelope Valley aquifer			
R20-95-15		NE NE NE NW sec 28, T. 120 N., R. 51 W.	44.4
R20-95-16		NE NE NE NW sec 28, T. 120 N., R. 51 W.	29.7
R20-95-17		SW NW SW SW sec. 36, T. 119 N., R. 51 W.	35.4
R20-95-18		SW NW SW SW sec. 36, T. 119 N., R. 51 W.	19.4
Bear Butte Creek Aquifer			
R20-95-97		SE NE NE NE sec. 6, T. 5 N., R. 6 E.	30.2
R20-95-100		NE NE NE SW sec. 16, T. 6 N., R. 7 E.	21.0
Big Sioux aquifer			
R20-89-37		NE SE SE SE sec. 9, T. 120 N., R. 52 W.	40.0
R20-89-40		NW SW NW NW sec. 21, T. 118 N., R. 52 W.	32.5
R20-89-42		NW SW NW NW sec. 21, T. 118 N., R. 52 W.	23.0
R20-89-43		SW SW SW SE sec. 15, T. 115 N., R. 52 W.	21.0
R20-89-44		SW SW SW SE sec. 15, T. 115 N., R. 52 W.	11.5
R20-89-45		SE SW SW SE sec. 10, T. 113 N., R. 51 W.	27.5
R20-89-46		SE SW SW SE sec. 10, T. 113 N., R. 51 W.	17.5
R20-89-47		NW NW NW NW sec. 18, T. 110 N., R. 50 W.	27.5
R20-89-48		NW NW NW NW sec. 18, T. 110 N., R. 50 W.	15.0
R20-89-49		SW SW SE NE sec. 7, T. 106 N., R. 48 W.	32.5
R20-89-50		SW SW SE NE sec. 7, T. 106 N., R. 48 W.	25.0
R20-89-54		SE SE SE SE sec. 8, T. 102 N., R. 49 W.	34.0
R20-89-55		SE SE SE SE sec. 8, T. 102 N., R. 49 W.	20.0
R20-89-56		NE SE SE NE sec. 8, T. 98 N., R. 48 W.	27.5
R20-89-57		NE SE SE NE sec. 8, T. 98 N., R. 48 W.	19.0
R20-89-59		SE SE SE SW sec. 24, T. 96 N., R. 48 W.	33.5
R20-89-60		SE SE SE SW sec. 24, T. 96 N., R. 48 W.	23.5
R20-89-63		SW SW SW SW sec. 31, T. 104 N., R. 49 W.	32.5
R20-89-64		SW SW SW SW sec. 31, T. 104 N., R. 49 W.	22.5
R20-89-65		SE SE SE SW sec. 2, T. 92 N., R. 49 W.	22.5
R20-89-67		SE SE SE SW sec. 2, T. 92 N., R. 49 W.	42.5
R20-93-30		NE SE SE SE sec. 9, T. 120 N., R. 52 W.	28.5
R20-94-01		SE SE SE SW sec. 4, T. 101 N., R. 48 W.	30.8
R20-94-02		SE SE SE SW sec. 4, T. 101 N., R. 48 W.	17.6
R20-94-04		NE NE NE SE sec. 10, T. 105 N., R. 49 W.	24.6
R20-94-05		NE NE NE SE sec. 10, T. 105 N., R. 49 W.	17.9
R20-94-06		NE NE NE SE sec. 9, T. 108 N., R. 49 W.	18.6
R20-94-07		NE NE NE SE sec. 9, T. 108 N., R. 49 W.	30.8
R20-94-08		SW SW SW SE sec. 27, T. 111 N., R. 49 W.	62.2
R20-94-09		SW SW SW SE sec. 27, T. 111 N., R. 49 W.	30.3
R20-94-12		SE SW SE SW sec. 24, T. 114 N., R. 52 W.	19.5
R20-94-13		NW NW NW NW sec. 14, T. 119 N., R. 52 W.	16.6
R20-94-14		SW SW SW SW sec. 21, T. 94 N., R. 48 W.	40.3
R20-94-15		SW SW SW SW sec. 21, T. 94 N., R. 48 W.	20.3
R20-94-23		NW NW SW SW sec. 29, T. 112 N., R. 50 W.	25.9
R20-94-24		NW NW SW SW sec. 29, T. 112 N., R. 50 W.	20.3

Table 1. (continued)

Aquifer and well name	Other well name	Well location	Well depth from casing top (ft)
Bowdle aquifer			
R20-89-06	L-3A	SW SW SW SW sec. 22, T. 119 N., R. 74 W.	41.3
R20-89-07	L-3B	SW SW SW SW sec. 22, T. 119 N., R. 74 W.	31.8
R20-89-09	L-5A	SE SE SE NE sec. 17, T. 119 N., R. 74 W.	26.6
R20-89-10	L-5B	SE SE SE NE sec. 17, T. 119 N., R. 74 W.	17.8
R20-90-15	L-8B	SE SW SE SW sec. 4, T. 120 N., R. 74 W.	55.0
R20-90-16	L-8A	SE SW SE SW sec. 4, T. 120 N., R. 74 W.	46.0
R20-96-19		SE NE SE NE sec. 24, T. 123 N., R. 74 W.	34.9
R20-96-20		SE NE SE NE sec. 24, T. 123 N., R. 74 W.	19.0
R20-96-21		NE NE NE NE sec. 15, T. 121 N., R. 74 W.	18.9
Cheyenne River aquifer			
R20-95-88		SW NW NE NE sec. 28, T. 7 S., R. 7 E.	15.0
R20-95-90		SE SE SW NE sec. 29, T. 6 S., R. 9 E.	22.0
Delmont aquifer			
R20-91-52	DC-1B	NE NE SE NE sec. 36, T. 98 N., R. 63 W.	35.0
R20-91-53	DC-1C	NE NE SE NE sec. 36, T. 98 N., R. 63 W.	25.0
R20-91-54	DC-2A	SE SE SE SW sec. 26, T. 98 N., R. 63 W.	29.4
R20-91-55	DC-2B	SE SE SE SW sec. 26, T. 98 N., R. 63 W.	20.0
Highmore-Blunt aquifer			
R20-96-26		SW SW SW SW sec. 4, T. 114 N., R. 74 W.	34.7
R20-96-27		SW SW SW SW sec. 4, T. 114 N., R. 74 W.	22.8
R20-96-29		NW SW NW NW sec. 2, T. 112 N., R. 76 W.	30.9
R20-96-30		NW SW NW NW sec. 2, T. 112 N., R. 76 W.	17.9
R20-96-31		SW NW NW NW sec. 15, T. 112 N., R. 73 W.	16.7
Missouri aquifer			
R20-95-04		SW SW SE NE sec. 35, T. 93 N., R. 54 W.	41.1
R20-95-05		SW SW SE NE sec. 35, T. 93 N., R. 54 W.	25.3
R20-95-06		SE SE SE NW sec. 14, T. 32 N., R. 4 E.	44.1
R20-95-07		SE SE SE NW sec. 14, T. 32 N., R. 4 E.	25.0
R20-95-08		SW SW SW SW sec. 15, T. 91 N., R. 50 W.	47.6
R20-95-09		SW SW SW SW sec. 15, T. 91 N., R. 50 W.	30.0
R20-95-11		SW SW SW NW sec. 28, T. 90 N., R. 49 W.	44.2
R20-95-12		SW SW SW NW sec. 28, T. 90 N., R. 49 W.	24.9
R20-95-13		NE NE NE NE sec. 17, T. 94 N., R. 54 W.	43.7
R20-95-14		NE NE NE NE sec. 17, T. 94 N., R. 54 W.	20.0

Table 1. (continued)

Aquifer and well name	Other well name	Well location	Well depth from casing top (ft)
Ogallala aquifer			
R20-94-30		SE SE SE SE sec. 17, T. 37 N., R. 34 W.	43.3
R20-94-31		SE SE SE SE sec. 17, T. 37 N., R. 34 W.	33.1
R20-94-32		NW NW NW NW sec. 3, T. 35 N., R. 27 W.	36.3
R20-94-33		NW NW NW NW sec. 3, T. 35 N., R. 27 W.	22.6
R20-94-34		SE SE SE NE sec. 29, T. 36 N., R. 29 W.	44.6
R20-94-35		SE SE SE NE sec. 29, T. 36 N., R. 29 W.	25.2
R20-94-36		SE SE SE SE sec. 6, T. 35 N., R. 30 W.	48.3
R20-94-37		SE SE SE SE sec. 6, T. 35 N., R. 30 W.	30.9
R20-94-38		NW NW NW NW sec. 23, T. 97 N., R. 77 W.	50.6
R20-94-39		NW NW NW NW sec. 23, T. 97 N., R. 77 W.	17.9
R20-94-40		NW NW NW NW sec. 29, T. 95 N., R. 76 W.	47.2
R20-94-41		NW NW NW NW sec. 29, T. 95 N., R. 76 W.	40.5
R20-94-50		NW SW SW NW sec. 6, T. 96 N., R. 71 W.	25.4
Parker-Centerville aquifer			
CO-83-149	TU-10A	NE NE NE NE sec. 29, T. 98 N., R. 52 W.	25.0
CO-83-158	TU-9A	SE SE SE SW sec. 18, T. 98 N., R. 52 W.	32.0
R20-88-10	TU-9B	SE SE SE SW sec. 18, T. 98 N., R. 52 W.	20.0
R20-88-11	TU-10B	NE NE NE NE sec. 29, T. 98 N., R. 52 W.	17.0
R20-90-09	TU-13B	NW NW NW NW sec. 24, T. 97 N., R. 52 W.	25.5
R20-90-10	TU-13A	NW NW NW NW sec. 24, T. 97 N., R. 52 W.	17.0
R20-96-12		SW SW SW SW sec. 2, T. 95 N., R. 52 W.	28.2
R20-96-13		SW SW SW SW sec. 2, T. 95 N., R. 52 W.	17.1
Rapid Creek aquifer			
R20-95-107		NW NW NW NW sec. 30, T. 1 S., R. 11 E.	25.6
R20-95-94		NW NE SW SE sec. 19, T. 1 N., R. 9 E.	17.4
Sand Hills aquifer			
R20-94-28		SW SE SE NW sec. 7, T. 35 N., R. 35 W.	41.9
R20-94-29		SW SE SE NW sec. 7, T. 35 N., R. 35 W.	23.8
Selby aquifer			
R20-96-22		SW SE SE SE sec. 16, T. 126 N., R. 76 W.	37.6
R20-96-23		SW SE SE SE sec. 16, T. 126 N., R. 76 W.	18.8
R20-96-24		SW NW SW NW sec. 9, T. 124 N., R. 76 W.	19.6
R20-96-25		SW NW SW NW sec. 9, T. 124 N., R. 76 W.	36.8

Table 1. (continued)

Aquifer and well name	Other well name	Well location	Well depth from casing top (ft)
Skunk Creek aquifer			
R20-94-17		NW NW NE NE sec. 18, T. 101 N., R. 50 W.	39.8
R20-94-18		NW NW NE NE sec. 18, T. 101 N., R. 50 W.	23.6
R20-94-19		SE SE SW NE sec. 25, T. 103 N., R. 51 W.	39.3
R20-94-20		SE SE SW NE sec. 25, T. 103 N., R. 51 W.	18.1
R20-94-21		NE NE NE SE sec. 8, T. 106 N., R. 52 W.	32.8
R20-94-22		NE NE NE SE sec. 8, T. 106 N., R. 52 W.	20.3
R20-94-26		NE NE NE SE sec. 23, T. 105 N., R. 51 W.	38.7
R20-94-27		NE NE NE SE sec. 23, T. 105 N., R. 51 W.	18.4
Spearfish Creek aquifer			
R20-95-102		SW NE NW NW sec. 9, T. 7 N., R. 2 E.	15.0
R20-95-103		NE NE SE SE sec. 33, T. 7 N., R. 2 E.	38.2
R20-95-104		NE NE SE SE sec. 33, T. 7 N., R. 2 E.	20.1
Tulare aquifer			
R20-96-32		SE SE SE SE sec. 15, T. 114 N., R. 62 W.	47.9
R20-96-33		SE SE SE SE sec. 15, T. 114 N., R. 62 W.	32.7
R20-96-34		NE NE NE NE sec. 23, T. 114 N., R. 63 W.	42.9
R20-96-35		NE NE NE NE sec. 23, T. 114 N., R. 63 W.	28.1
R20-96-36		SW SW SW SW sec. 23, T. 115 N., R. 63 W.	35.2
R20-96-37		SW SW SW SW sec. 23, T. 115 N., R. 63 W.	24.6
Vermillion-East-Fork aquifer			
R20-96-14		SE SE NE SE sec. 6, T. 111 N., R. 56 W.	39.8
R20-96-15		SE SE NE SE sec. 6, T. 111 N., R. 56 W.	29.4
R20-96-17		SE SW SE SW sec. 7, T. 115 N., R. 57 W.	33.5
R20-96-18		SE SW SE SW sec. 7, T. 115 N., R. 57 W.	16.3
Vermillion-West-Fork aquifer			
R20-88-01	TU-1B	SW NW SW NW sec. 15, T. 99 N., R. 53 W.	20.0
TU-80C	TU-1A	SW NW SW NW sec. 15, T. 99 N., R. 53 W.	25.5

Table 2. Summary nitrate data by well

Aquifer and well	Minimum	Median	Maximum	Number of samples
Antelope Valley aquifer				
R20-95-16	16.2	16.5	16.8	2
R20-95-15	<0.1	0.1	0.1	2
R20-95-18	8.5	11.2	13.9	2
R20-95-17	0.1	0.2	0.3	2
Bear Butte Creek aquifer				
R20-95-97	3.0	3.4	3.8	2
R20-95-100	0.1	4.6	5.0	5
Big Sioux aquifer				
R20-89-42	1.83	8.8	18.4	56
R20-89-40	≤0.78	4.0	11.2	21
R20-89-44	<0.04	0.1	1.31	21
R20-89-43	0.07	1.1	4.90	21
R20-89-46	0.04	1.0	7.09	21
R20-89-45	<0.04	<0.04	0.2	21
R20-89-48	0.07	0.9	2.42	21
R20-89-47	<0.04	<0.04	0.17	21
R20-89-50	<0.04	0.1	3.48	34
R20-89-49	<0.04	<0.04	0.94	34
R20-89-55	<0.04	<0.04	0.31	24
R20-89-54	<0.04	<0.04	0.43	24
R20-89-57	0.90	6.5	25.0	52
R20-89-56	<0.04	<0.04	0.42	20
R20-89-60	0.34	7.3	14.3	59
R20-89-59	<0.04	<0.04	0.2	30
R20-89-64	1.02	8.6	20.1	67
R20-89-63	2.72	6.6	13.0	67
R20-89-65	0.4	6.1	17.6	53
R20-89-67	<0.04	<0.04	0.50	19
R20-93-30	14.30	20.3	28.9	37
R20-89-37	<0.04	<0.04	0.3	45
R20-94-02	<0.04	<0.04	0.2	7
R20-94-01	<0.04	<0.04	0.2	7
R20-94-05	1.72	4.1	4.68	7
R20-94-04	0.17	0.9	1.11	7
R20-94-06	3.21	9.8	15.1	7
R20-94-07	<0.04	<0.04	0.2	7
R20-94-09	19.30	21.4	30.2	7
R20-94-08	<0.04	<0.04	0.1	7
R20-94-12	13.0	19.7	47.2	13
R20-94-13	0.27	1.6	4.63	7
R20-94-15	6.81	8.1	11.6	7
R20-94-14	0.70	1.7	2.4	7
R20-94-24	1.6	3.2	4.14	7
R20-94-23	<0.04	0.2	0.8	7

Table 2. (continued)

Aquifer and well	Minimum	Median	Maximum	Number of samples
Bowdle aquifer				
R20-89-07	1.31	2.0	4.9	14
R20-89-06	0.13	0.3	0.5	14
R20-89-10	2.0	6.8	16.5	4
R20-89-09	0.2	1.1	5.39	4
R20-90-16	3.2	5.6	9.33	16
R20-90-15	3.35	13.0	29.8	16
R20-96-20	7.0	---	7.0	1
R20-96-19	0.1	---	0.1	1
R20-96-21	10.3	---	10.3	1
Cheyenne River aquifer				
R20-95-88	0.7	0.8	0.9	2
R20-95-90	<0.1	0.1	0.1	2
Delmont aquifer				
R20-91-53	0.1	9.5	19.1	4
R20-91-52	<0.1	0.5	2.28	4
R20-91-55	26.10	33.3	50.5	7
R20-91-54	0.1	0.3	0.76	7
Highmore-Blunt aquifer				
R20-96-27	0.9	---	0.9	1
R20-96-26	2.8	---	2.8	1
R20-96-30	0.5	---	0.5	1
R20-96-29	0.7	---	0.7	1
R20-96-31	0.1	---	0.1	1
Missouri aquifer				
R20-95-05	0.1	0.2	0.2	2
R20-95-04	0.1	0.1	0.1	2
R20-95-07	0.1	0.5	0.9	2
R20-95-06	0.1	0.1	0.1	2
R20-95-09	0.1	0.2	0.2	2
R20-95-08	0.1	0.1	0.1	2
R20-95-12	0.1	0.1	0.1	2
R20-95-11	0.1	0.2	0.2	2
R20-95-14	36.3	36.9	37.4	2
R20-95-13	1.7	2.7	3.7	2
Ogallala aquifer				
R20-94-31	2.0	2.3	2.76	4
R20-94-30	2.3	2.5	2.81	4
R20-94-33	2.0	2.7	7.93	4
R20-94-32	1.0	1.0	1.1	4
R20-94-35	0.44	2.2	3.1	9
R20-94-34	0.83	1.3	1.6	9
R20-94-37	2.8	3.9	5.49	4
R20-94-36	0.42	0.8	1.5	4

Table 2. (continued)

Aquifer and well	Minimum	Median	Maximum	Number of samples
Ogallala aquifer (continued)				
R20-94-39	0.66	25.1	30.8	9
R20-94-38	1.3	1.4	1.72	9
R20-94-41	22.1	125	145	10
R20-94-40	6.4	7.6	8.1	10
R20-94-50	3.33	3.5	5.7	4
Parker-Centerville aquifer				
R20-88-10	2.0	4.1	22.4	16
CO-83-158	<0.04	<0.04	0.1	16
R20-88-11	0.31	1.2	5.15	14
CO-83-149	<0.04	0.1	0.84	14
R20-90-10	4.23	5.0	10.7	4
R20-90-09	<0.04	<0.04	0.1	4
R20-96-13	0.6	---	0.6	1
R20-96-12	0.1	---	0.1	1
Rapid Creek aquifer				
R20-95-94	<0.1	0.1	0.2	5
R20-95-107	0.8	1.0	1.2	2
Sand Hills aquifer				
R20-94-29	0.2	0.7	3.25	4
R20-94-28	0.66	0.8	0.9	4
Selby aquifer				
R20-96-23	0.7	---	0.7	1
R20-96-22	0.1	---	0.1	1
R20-96-24	1.4	---	1.4	1
R20-96-25	<0.1	---	<0.1	1
Skunk Creek aquifer				
R20-94-18	2.7	3.8	10.9	12
R20-94-17	<0.04	<0.1	0.1	12
R20-94-20	<0.04	<0.1	0.39	9
R20-94-19	<0.04	<0.1	0.1	9
R20-94-22	0.50	1.0	1.3	4
R20-94-21	<0.04	<0.04	0.1	4
R20-94-27	3.28	3.5	4.45	4
R20-94-26	<0.04	<0.04	0.1	4
Spearfish Creek aquifer				
R20-95-102	<0.1	0.2	5.4	5
R20-95-104	0.7	1.1	1.3	5
R20-95-103	0.9	1.2	2.0	5

Table 2. (continued)

Aquifer and well	Minimum	Median	Maximum	Number of samples
Tulare aquifer				
R20-96-32	0.1	---	0.1	1
R20-96-35	3.0	---	3.0	1
R20-96-34	0.1	---	0.1	1
R20-96-37	26.6	---	26.6	1
R20-96-36	0.1	---	0.1	1
Vermillion-East-Fork aquifer				
R20-96-15	2.6	---	2.6	1
R20-96-14	<0.1	---	<0.1	1
R20-96-18	18.1	---	18.1	1
R20-96-17	<0.1	---	<0.1	1
Vermillion-West-Fork aquifer				
R20-88-01	6.3	8.6	11.1	7
TU-80C	2.7	5.1	7.19	7

Note: Wells located at the same monitoring site are placed within horizontal lines with the shallow well listed above the deep well.

--- Indicates that a median could not be calculated due to a lack of data.

All concentrations reported in milligrams per liter

For analyses for which there was no detection, one half the value of the detection limit was used for generating statistics.

Nitrate = nitrate plus nitrite as nitrogen

Table 3. Information about pesticides for which analyses were performed

Pesticide	Trade Name ¹	Persistence	Mobility	MCL (ug/L) ²	LTHA (ug/L) ³	Use
Acetochlor	---	---	---	---	---	herbicide
Alachlor	Lasso	N	SM	2	---	herbicide
Atrazine	Aatrex	P (at high pH)	SM	3	---	herbicide
Desethyl Atrazine	---	---	---	---	---	(transformation product)
Deisopropyl Atrazine	---	---	---	---	---	(transformation product)
Bentazon	Basagran	N	NI	---	300	Herbicide
Bromoxynil	Butril	N	SM	---	---	Herbicide
Butylate	Sutan	N	NI	---	4000	Herbicide
Carbofuran	Furadan	M	M	40	---	Insecticide
Chlorpyrifos	Lorsban	---	---	---	---	Insecticide
Cyanazine	Bladex	N	SM	-----	1	Herbicide
2,4-D	Miracle	N	MM	70	---	Herbicide
DCPA	Dacthal	---	---	---	4000	Herbicide
Dicamba	Banvel	N	VM	---	200	Herbicide
Dimethazone (Clomozone)	Command	M	MM	---	---	herbicide
EPTC	Eradicane	N	NI	---	---	herbicide
Ethalfuralin	Sonalan	M	I	---	---	herbicide
Ethoprop	Mocap	---	---	---	---	insecticide
Fonofos	Dyfonate	M	MM	---	10	insecticide
Glyphosate	Roundup	M	I	700	---	herbicide
Imazaquin	Scepter	---	---	---	---	herbicide
MCPA	MCPA	M	MM	---	10	herbicide
Metolachlor	Dual	M	NI	---	100	herbicide
Metribuzin	Sencor	M	MM	---	200	herbicide
Parathion	Parathion	N	I	---	---	insecticide
Pendimethalin	Prowl	M	NI	---	---	herbicide
Phorate	Thimet	N	NI	---	---	insecticide
Picloram	Tordon	P	MM	500	---	herbicide
Prometon	Pramitol	---	---	---	100	herbicide
Propachlor	Ramrod	N	SM	---	90	herbicide
Quizalfopethyl	Assure	---	---	---	---	Herbicide
Simazine	Princep	P	SM	4	---	Herbicide
Terbufos	Counter	N	NI	---	0.9	Insecticide
2,4,5-TP	Silvex	---	---	50	---	Banned
Triasulfuron	Amber	---	---	---	---	Herbicide
Trifluralin	Treflan	M	---	---	5	Herbicide

P = Persistent, M = Moderately persistent, N = Not persistent, VM = Very mobile, MM = Moderately mobile, SM = Slightly mobile, NI = Nearly immobile, I = immobile

- 1 Other trade names may exist
 - 2 MCL (ug/L) = maximum contaminant level in micrograms per liter
 - 3 LTHA (ug/L) = lifetime health advisory in micrograms per liter
- Information not established

Table modified from McBride, Peterson, and Lamay, 1988

Table 4. Maximum and minimum concentrations and number of samples for selected inorganic parameters listed by aquifer

Aquifer		Iron	Manganese	Sulfate	Chloride	Nitrate	Ammonia	TDS	Hardness
Antelope Valley	Max	0.16	0.45	73.4	8	16.8	<0.02	415	358
	Min	<0.06	<0.02	<10.0	<3.0	<0.1	<0.02	309	246
	n	8	8	8	8	8	8	8	8
Bear Butte Creek	Max	0.11	0.06	1188	59	5.0	0.03	2183	1302
	Min	<0.06	0.02	331	41	0.1	<0.02	858	625
	n	4	4	4	4	7	7	4	4
Big Sioux	Max	7.57	2.86	371	54	47.2	1.78	955	710
	Min	≤0.04	<0.02	17.9	1.4	<0.04	0	229	191
	n	269	269	290	290	872	707	290	290
Bowdle	Max	0.27	1.12	267	73	29.8	0.16	949	710
	Min	<0.05	<0.02	<10.0	1	0.1	<0.02	317	215
	n	27	27	27	27	71	71	27	27
Cheyenne River	Max	1.65	0.97	1493	172	0.9	0.97	2811	1001
	Min	0.13	0.66	1369	19	<0.1	<0.02	2564	932
	n	4	4	4	4	4	4	4	4
Delmont	Max	1.81	1.3	569	22	50.5	0.33	1149	774
	Min	<0.05	<0.02	179	7.4	<0.1	<0.02	768	522
	n	16	16	16	16	22	22	16	16
Highmore-Blunt	Max	1.99	1.13	792	52	2.8	1.29	1696	418
	Min	<0.06	<0.02	23.9	<3.0	0.1	<0.02	266	212
	n	5	5	5	5	5	5	5	5
Missouri	Max	13.8	4.32	434	20	37.4	0.86	959	603
	Min	<0.06	<0.02	<10.0	5	0.1	<0.02	204	174
	n	20	20	20	20	20	20	20	20
Ogallala	Max	<0.06	0.14	383	9.4	145	<0.05	1308	631
	Min	<0.05	<0.02	≤4.3	≤0.8	0.42	<0.02	142	42
	n	52	52	52	52	84	84	52	52
Parker-Centerville	Max	3.33	1.11	541	31	22.4	0.23	1069	761
	Min	<0.05	<0.02	127	5.9	<0.04	<0.02	548	414
	n	26	26	26	26	70	70	26	26

Table 4. (continued)

Aquifer		Iron	Manganese	Sulfate	Chloride	Nitrate	Ammonia	TDS	Hardness
Rapid Creek	Max	0.63	0.37	599	70	1.2	0.03	1207	798
	Min	≤0.05	0.25	372	26	<0.1	<0.02	924	514
	n	4	4	4	4	7	7	4	4
Sand Hills	Max	<0.06	0.03	127	≥1.7	3.25	<0.05	329	155
	Min	<0.05	<0.02	≤5.3	0.6	0.2	<0.02	110	38
	n	8	8	8	8	8	8	8	8
Selby	Max	5.52	2.11	962	28	1.4	0.31	1785	857
	Min	≤0.03	<0.02	78.4	5	<0.1	<0.02	345	275
	n	4	4	4	4	4	4	4	4
Skunk Creek	Max	3.91	5.62	820	44	10.9	1.43	1470	990
	Min	<0.05	<0.02	28.2	4.9	<0.04	<0.02	332	277
	n	32	32	32	32	58	58	32	32
Spearfish Creek	Max	4.72	0.68	976	31	5.4	0.1	1926	1373
	Min	<0.06	0.02	35.7	8	<0.1	<0.02	341	313
	n	6	6	6	6	15	15	6	6
Tulare	Max	12.1	2.66	952	246	26.6	0.49	2121	1069
	Min	0.02	<0.02	113	7	0.1	<0.02	434	358
	n	5	5	5	5	5	5	5	5
Vermillion-East-Fork	Max	2.07	0.91	246	8	18.1	0.55	675	482
	Min	<0.06	<0.02	27.4	<3.0	<0.1	<0.02	352	298
	n	4	4	4	4	4	4	4	4
Vermillion-West-Fork	Max	1.29	<0.05	280	25.2	11.1	<0.05	792	550
	Min	<0.05	<0.02	182	19.4	2.7	<0.02	606	440
	n	6	6	6	6	14	14	6	6

Max = maximum concentration reported

Min = minimum concentration reported

N = number of samples taken

All concentrations reported in milligrams per liter

Table 5. List of volatile organic compounds for which analyses were performed

Benzene
Carbon tetrachloride
para-Dichlorobenzene
ortho-Dichlorobenzene
1,2-Dichloroethane
1,1-Dichloroethylene
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
Dichloromethane
1,2-Dichloropropane
Ethylbenzene
Monochlorobenzene
Styrene
Tetrachloroethylene
Toluene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Vinyl chloride
Xylenes (total)