WATER-QUALITY ASSESSMENT OF THE RIO GRANDE VALLEY, COLORADO, NEW MEXICO, AND TEXAS–SHALLOW GROUND-WATER QUALITY OF A LAND-USE AREA IN THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO, 1993

By Scott K. Anderholm

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4144

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

U.S. DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

Albuquerque, New Mexico
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4501 Indian School Road NE, Suite 200
Albuquerque, NM 87110-3929

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resource Locator (URL) at:
<http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

CONTENTS

FIGURES

FIGURES--Concluded

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
quart	0.9464	liter
gallon	3.785	liters
pound	0.4536	kilograms
acre	4,047	square meter
acre-foot	0.001233	cubic hectometer
gallons per minute	0.06309	liter per second

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the equation:

$$^{\circ}F = 9/5\ (^{\circ}C) + 32$$

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

WATER-QUALITY ASSESSMENT OF THE RIO GRANDE VALLEY, COLORADO, NEW MEXICO, AND TEXAS - SHALLOW GROUND-WATER QUALITY OF A LAND-USE AREA IN THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO, 1993

By Scott K. Anderholm

ABSTRACT

This report describes the quality of shallow ground water in an agricultural area in the San Luis Valley, Colorado, and discusses how natural and human factors affect the quality of shallow ground water. Thirty-five wells were installed, and water samples were collected from these wells and analyzed for selected dissolved common constituents, nutrients, trace elements, radionuclides, and synthetic organic compounds.

The San Luis Valley is a high intermontane valley that is partially drained by the Rio Grande. The San Luis Valley land-use study area was limited to a part of the valley where the depth to water is generally less than 25 feet. The area where the 35 monitor wells were installed was further limited to the part of the study area where center-pivot overhead sprinklers are used to irrigate crops. Precipitation, runoff from adjacent mountainous areas, and ground-water inflow from the adjacent mountainous areas are the main sources of water to the aquifers in the San Luis Valley. Discharge of water from the shallow, unconfined aquifer in the valley is mainly from evapotranspiration. The dominant land use in the San Luis Valley is agriculture, although nonirrigated land and residential land are interspersed with agricultural land. Alfalfa, native hay, barley, wheat, potatoes, and other vegetables are the main crops.

Dissolved-solids concentrations in shallow ground water sampled ranged from 75 to 1,960 milligrams per liter. The largest median concentration of cations was for calcium, and the largest median concentration of anions was for bicarbonate in shallow ground water in the San Luis Valley. Calcium concentrations ranged from 7.5 to 300 milligrams per liter, and bicarbonate concentrations ranged from 28 to 451 milligrams per liter. Nitrite plus nitrate concentrations ranged from less than 0.1 to 58 milligrams per liter as N; water from 11 wells had nitrite plus nitrate concentrations greater than 10 milligrams per liter as N. With the exception of the following trace elements--aluminum, barium, iron, manganese, molybdenum, and uranium--the concentrations of trace elements were less than 10 micrograms per liter in 90 percent of the samples. All trace-element concentrations measured were below the maximum contaminant levels set by the U.S. Environmental Protection Agency. Five samples exceeded the proposed maximum contaminant level of 0.02 milligram per liter for uranium. All samples collected exceeded the proposed maximum contaminant level for radon-222. The volatile organic compound methyltertbutylether was detected in one sample at a concentration of 0.6 microgram per liter. Of the pesticides analyzed for, one or more were detected in water from 5 of the 35 wells sampled. Metribuzin was the most commonly detected pesticide and was detected in water from three wells at concentrations ranging from an estimated 0.005 to 0.017 microgram per liter. Metolachlor (detected in one sample at a concentration of 0.072 microgram per liter), prometon (detected in one sample at a concentration of 0.01 microgram per liter), and p,p'-DDE (detected in one sample at an estimated concentration of 0.002 microgram per liter) were the other pesticides detected. The U.S. Environmental Protection Agency lifetime health advisories for metolachlor, metribuzin, and prometon is 100 micrograms per liter, which is much larger than the concentrations measured in the shallow ground water sampled for this study.

The elevated nitrite plus nitrate concentrations in shallow ground water are indicative of leaching of fertilizers from the land surface. This conclusion is consistent with conclusions made in other investigations of the San Luis Valley. On the basis of areal distribution and range of trace-element concentrations, human activities have not caused widespread trace-element contamination in the shallow ground water. The main factors affecting trace-element concentrations in shallow ground water are solubility equilibria, variation in the distribution of minerals in the aquifer, formation of organic complexes, formation of carbonate complexes, and the oxidation-reduction state of the ground water/aquifer. Gross alpha and gross beta activities measured in ground water are from naturally occurring elements (primarily uranium and potassium-40). Relatively few synthetic organic compounds were detected in shallow ground water, indicating that human activities have not resulted in widespread contamination of the shallow part of the aquifer by synthetic organic compounds.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began to implement the full-scale National Water-Quality Assessment (NAWQA) program. The Rio Grande Valley (fig. 1) was one of the first 20 NAWQA study units selected for study of the status of and trends in the quality of ground water and surface water. One of the goals of the NAWQA program is to provide a scientific understanding of the natural and human factors affecting the quality of ground water in the Nation.

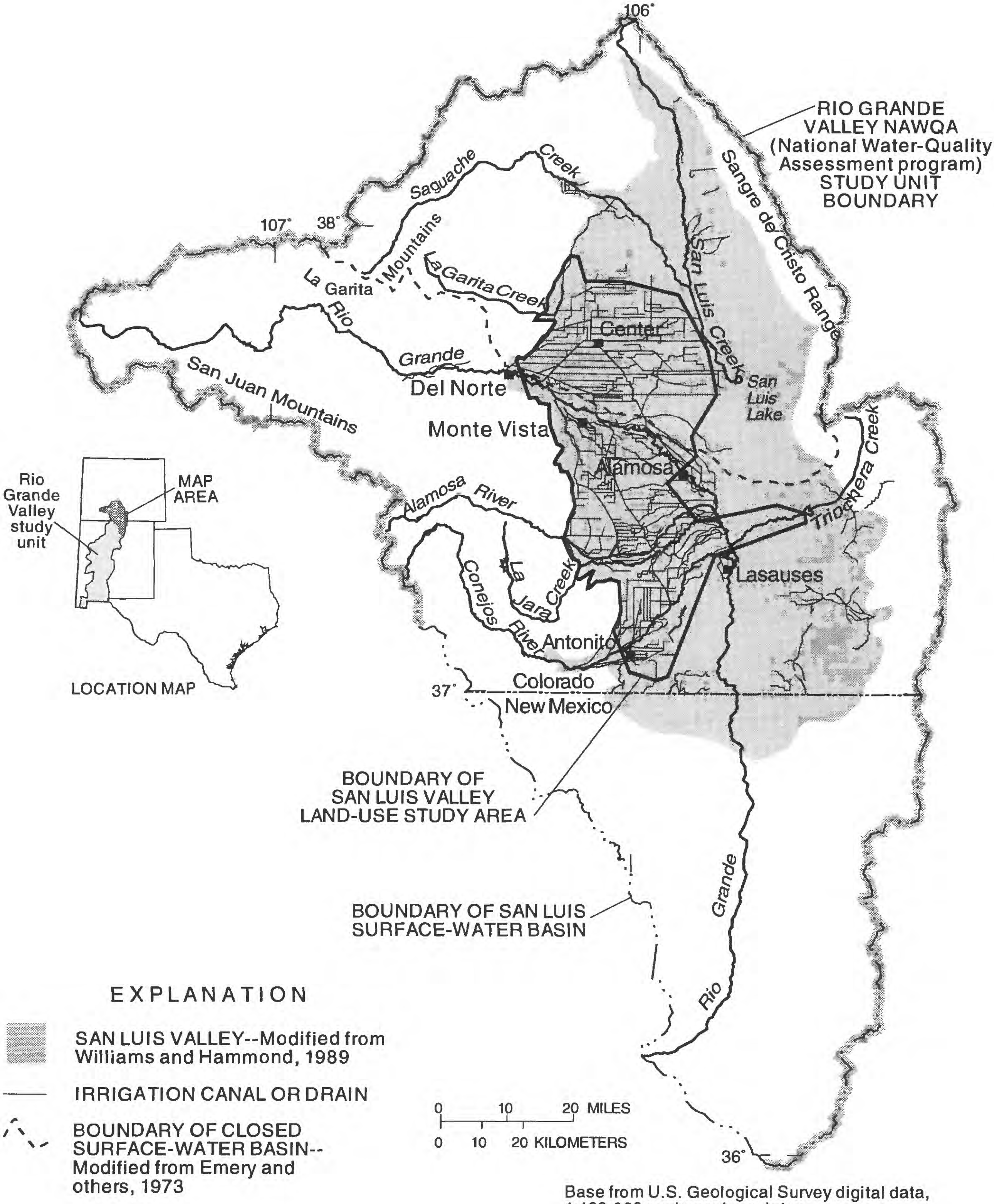
The San Luis surface-water basin, which includes the San Luis Valley, is the northernmost surface-water basin in the Rio Grande Valley (fig. 1). The San Luis Valley is a high intermontane valley that has been farmed for more than 100 years. A part of the San Luis Valley where the depth to water is generally less than 25 feet and center-pivot overhead sprinklers are used to irrigate crops was studied to determine shallow ground-water quality and factors affecting shallow ground-water quality.

Purpose and Scope

This report describes the quality of shallow ground water in an agricultural area in the San Luis Valley, Colorado, and discusses how natural and human factors affect the quality of shallow ground water. The report presents the analyses of water samples collected from 35 shallow wells that were installed in August 1993. Water samples were collected from the wells in August and September 1993 and were analyzed for selected common ions, nutrients, trace elements, radionuclides, and various synthetic organic compounds. The analytical results are presented in graphs and tables.

Previous Work

Many hydrologic investigations have been done in the San Luis Valley because of the long history of water use in the area and the importance of water for irrigation of crops. Some of the more detailed reports on the hydrology of the area include Siebenthal (1910), Robinson and Waite (1938), Powell (1958), Emery and others (1975), Huntley, (1976), and Hearne and Dewey (1988). Water quality also was discussed by these authors except Hearne and Dewey. Investigations that focused specifically on water quality as related to land use in the San Luis Valley include Edelmann and Buckles (1984), Williams and Hammond (1989), Durnford and others (1990), Ellerbroek and others (1992), Eddy-Miller (1993), Thompson (1993), and LeStrange (1995).



Base from U.S. Geological Survey digital data, 1:100,000 scale, various dates

Universal Transverse Mercator projection, zone 13

Figure 1.--Location of the San Luis Valley land-use study area.

Acknowledgments

The Board of Directors of the Rio Grande Water Conservation District and General Manager Mr. Ralph Curtis were instrumental in soliciting land-owner cooperation. Without the cooperation of the land owners who allowed installation of monitor wells on their property, the study could not have been conducted. Land-owner cooperation and support are greatly appreciated. The author also thanks the staff of the Colorado Division of Water Resources, Division III office in Alamosa, for their time and assistance in permitting the monitor wells.

DESCRIPTION OF THE STUDY AREA

The San Luis Valley, which is about 150 miles long and 50 miles wide, is bounded on the east by the Sangre de Cristo Range and on the west by the San Juan and La Garita Mountains (fig. 1). The floor of the valley is relatively flat and has an average altitude of about 7,700 feet. Several of the peaks in the rugged mountains that bound the valley have altitudes greater than 14,000 feet. The southern part of the San Luis Valley is drained by the Rio Grande. The northern part of the valley has closed surface-water drainage and is referred to as the closed basin. The closed basin, which also has closed ground-water flow in the unconfined aquifer, is separated from the Rio Grande drainage by a low topographic divide and a ground-water hydrologic divide in the unconfined aquifer.

The area of study was limited to a part of the San Luis Valley where the depth to water is generally less than 25 feet as shown on figure 1 by the boundary of the San Luis Valley land-use study area. Within the study area boundary are areas of irrigated land, residential land, and nonirrigated land. Monitor wells were installed near center-pivot overhead sprinklers that are used to irrigate crops. The following discussion is not limited to the study area because it is important to understand the hydrogeologic framework of the entire San Luis Valley and how the area of study is affected by general hydrologic conditions in the valley and agricultural land use.

Climate

The climate of the San Luis Valley is arid to semiarid and is characterized by sunny days, large daily temperature ranges, low humidity, and mean annual potential evapotranspiration that exceeds mean annual precipitation. The mean annual temperature from 1961 to 1990 at Alamosa is 41 $^{\circ}$F; July is the warmest month and January and December are the coolest months (National Oceanic and Atmospheric Administration, no date). Evapotranspiration from a class-A pan from April through October 1960 to 1980 at Alamosa averaged 57 inches (Leonard and Watts, 1989, p. 9). The mean annual precipitation averaged 7.57 inches from 1961 to 1990 (National Oceanic and Atmospheric Administration, no date). A precipitation deficit (potential evapotranspiration minus precipitation) occurs every month of the year; the largest deficit is in June (Leonard and Watts, 1989). The large precipitation deficit requires irrigation of crops throughout the growing season.

The climate of the mountainous areas adjacent to the San Luis Valley is much colder and wetter than the climate of the valley. Precipitation in the San Juan Mountains can exceed 30 inches per year (Hearne and Dewey, 1988). Much of the precipitation falls in the winter as snow. Runoff of snowmelt from the mountains to the San Luis Valley is considerable.

Surface-Water System

Runoff through streams and rivers from the mountainous areas and ground-water recharge are important sources of water to the San Luis Valley. The San Luis Valley has two distinct areas of surface-water drainage: the part drained by the Rio Grande and its tributaries and the closed basin (fig. 1). The Rio Grande enters the San Luis Valley from the west and flows southeastward to Alamosa, then southward out of the valley. Other tributary basins to the valley include the Conejos and Alamosa River Basins and La Jara Creek Basin in the San Juan Mountains and Trinchera Creek Basin in the Sangre de Cristo Range. With the exception of the Conejos River Basin, these basins generate considerable amounts of water, but leaky channels on the valley floor cause La Jara Creek, Trinchera Creek, and the Alamosa River to largely dissipate before flows reach the Rio Grande. These hydrologic conditions were recognized in the Rio Grande Compact (Rio Grande Compact Commission, 1994) where La Jara Creek, Trinchera Creek, and the Alamosa River were considered nontributary to the Rio Grande for purposes of water administration. Part of the water in the Rio Grande and its tributaries is diverted into irrigation canals during the irrigation season. The system of irrigation canals in the San Luis Valley is extensive (fig. 1), and much of the system was in place by 1900 (Siebenthal, 1910, p. 19). Some of the surface water diverted into irrigation canals leaks through the bed of the canals and recharges the aquifer. Some of the surface water is also diverted into pits where the water recharges the aquifer. Several large diversions on the Rio Grande divert water into the closed basin. Saguache, San Luis, and La Garita Creeks are the main natural streams that flow into the closed basin; however, many smaller streams also enter the closed basin from the Sangre de Cristo Mountains. San Luis Lake, which is located near the lowest part or sump area of the closed basin, is the largest of several lakes in the closed basin area.

Hydrogeology

A large thickness of basin-fill deposits, up to 19,000 feet (Burroughs, 1981), in the San Luis Valley consists of interbedded clay, silt, sand, gravel, and volcanic rocks. These deposits form the aquifers in the San Luis Valley. The two main aquifers, the confined aquifer and the unconfined aquifer, are separated by a confining layer in the valley (fig. 2). This confining layer, which underlies a large part of the center of the valley, consists of a series of discontinuous clay beds and volcanic rocks (Emery and others, 1973, p. 12). The top of the confining bed is about 60 to 100 feet below land surface (Emery and others, 1973). The confined aquifer is not present along the margins of the valley. Two separate flow systems are in the unconfined aquifer: one system in the closed basin part of the San Luis Valley and one system south of the closed basin. Although there are two separate flow systems in the unconfined aquifer, the processes of recharge to and discharge from the two systems are similar.

Recharge to the confined aquifer occurs along the margins of the San Luis Valley from infiltration of precipitation, infiltration of surface water, and inflow of ground water from the adjacent mountains (fig. 2). Discharge from the confined aquifer results from ground-water withdrawals, ground-water flow to the south, and upward leakage through the confining bed (Huntley, 1976, p. 158). Ground-water movement is from the basin margins toward the sump area.

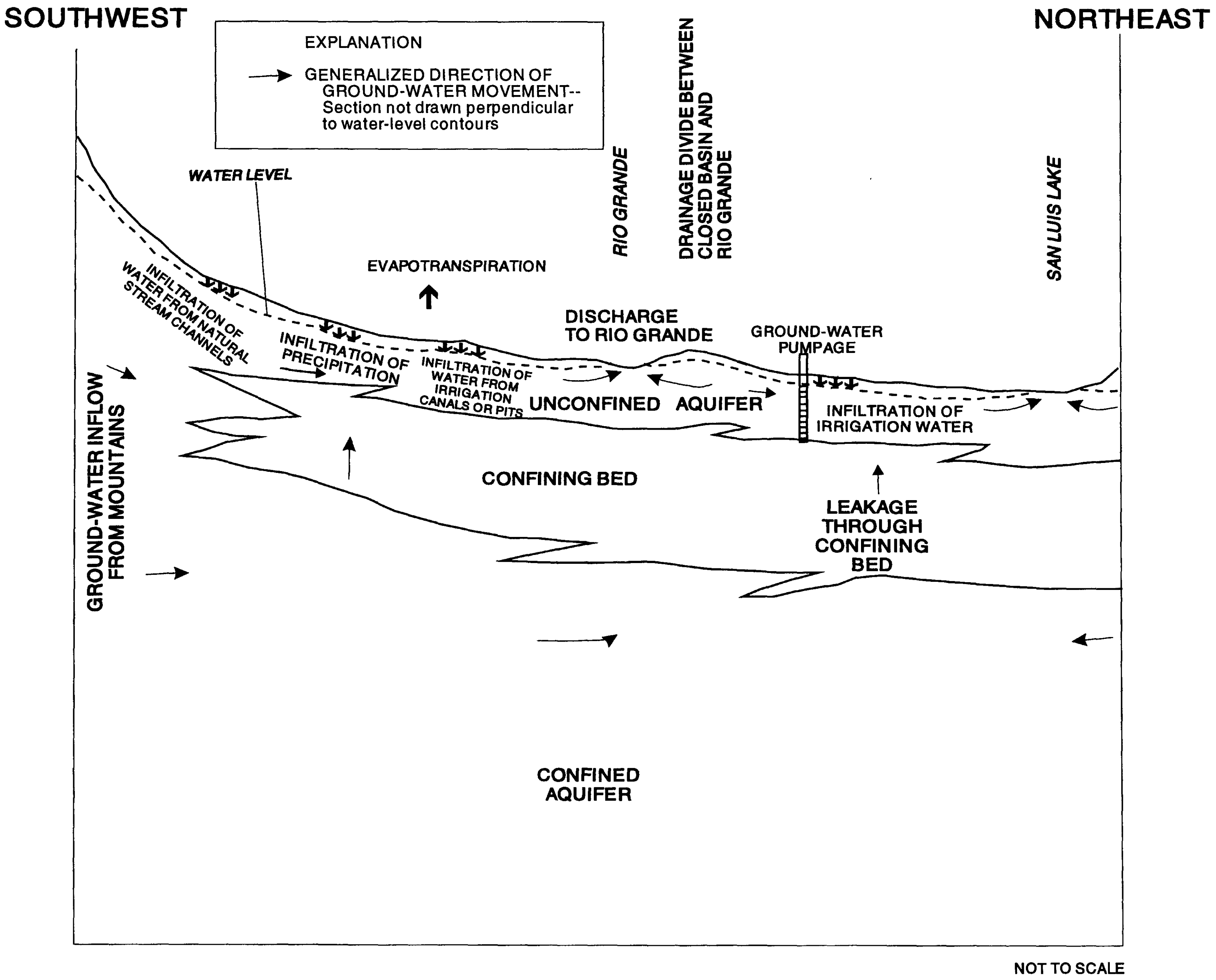


Figure 2.--Generalized geohydrologic section illustrating the hydrologic system of the San Luis Valley.

Recharge to the unconfined aquifer is the result of infiltration of precipitation, infiltration of surface water from natural stream channels and from irrigation canals, infiltration of irrigation water applied to crops (net irrigation recharge), inflow of ground water from the adjacent mountains, and upward leakage of ground water through the confining bed (Powell, 1958, p. 62-69). Recharge of surface water diverted from rivers and creeks is an important source of recharge to the unconfined aquifer. In some areas of the valley, surface water is diverted into pits where the water infiltrates and recharges the aquifer.

Discharge from the unconfined aquifer includes evapotranspiration, ground-water discharge to streams or drains, ground-water withdrawals, and ground-water flow to the south. A large amount of evapotranspiration occurs in the San Luis Valley because the water table is near the land surface in much of the area and because a large amount of water is applied to crops. The process of evapotranspiration affects shallow ground-water quality, and therefore, is discussed in detail. In nonirrigated areas, water that evapotranspires is from precipitation and directly from the water table. In areas of irrigated agriculture, water that evapotranspires can be from precipitation, surface water applied to the fields, ground water from the unconfined aquifer where plants roots are below the water table, or ground water pumped from the unconfined or confined aquifers and applied to fields. Although infiltration of irrigation water pumped from the aquifer results in recharge, the net effect on the amount of ground water in the basin is a decrease because of the amount of water that evapotranspires. For example, if 3 acre-feet of water is pumped from the aquifer and applied to a field and 2 acre-feet of this water evapotranspires, only 1 acre-foot is left to infiltrate and recharge the aquifer. Most of the original solutes in the original 3 acre-feet of water, however, remain in the soil zone or aquifer.

Ground water in the unconfined aquifer flow system in the closed basin flows from the basin margins toward the sump area, which is near San Luis Lake. The ground-water divide that separates the flow system in the unconfined aquifer in the closed basin from the flow system in the unconfined aquifer south of the closed basin is 1 to 4 miles north of the Rio Grande and parallels the Rio Grande (Emery and others, 1973, pl. 1). Ground water in the unconfined aquifer flow system south of the closed basin flows from the ground-water divide or basin margins toward the Rio Grande or major rivers and then southward.

Several hydrologic budgets done for areas of the San Luis Valley by different investigators estimated the amount of inflow and outflow to the aquifers (table 1). Because of relatively little change in ground-water storage from one year to the next (Hearne and Dewey, 1988), inflow of water to the valley approximately equals ground-water outflow, surface-water outflow, and evapotranspiration. The budgets demonstrate that the large amount of inflow is mainly removed from the valley as the result of evapotranspiration (table 1). Emery and others (1973) estimated that the total amount of evapotranspiration for the Colorado part of the San Luis Valley (most of the San Luis Valley) was 2,420,000 acre-feet per year from 1924 to 1969. Huntley (1976) estimated evapotranspiration for the closed basin part of the San Luis Valley to be 1,847,000 acre-feet per year. Hearne and Dewey (1988, p. 49) estimated the total amount of evapotranspiration from a large part of the San Luis Valley to be 2,900,000 acre-feet per year from 1950 through 1980.

Table 1.--Water balances for parts of the San Luis Valley

[All values in acre-feet per year; original data converted to acre-feet per year; --, no data; (1), not estimated]

	Outflow			Inflow		
	Ground-water outflow	Surface-water outflow	Evapo-transpi-ration	Surface water plus ground water	Precip-itation	Change in ground-water storage
Emery and others (1973, p. 4) Colorado part of San Luis Valley	50,000	330,000	2,420,000	1,580,000	1,220,000	--
Huntley (1976, p. 32) Closed basin part of San Luis Valley	0	0	1,848,000	1,081,000	765,000	--
Hearne and Dewey (1988, p. 49)	(1)	253,000	2,823,000	2,273,000	1,086,000	63,000

The large inflow of water and subsequent evapotranspiration result in large amounts of solutes remaining because evapotranspiration removes only water. This is especially important in the closed basin where these solutes are concentrating because there is no natural outflow of surface water or ground water to remove solutes from the basin. The Closed Basin Division is a project that was designed to pump ground water from the unconfined aquifer in the sump area of the closed basin that otherwise would be lost to evaporation into the Rio Grande (Bureau of Reclamation, 1987). Solutes would be removed from the closed basin as the result of this project. For Colorado to receive credit for delivery of this water to New Mexico and Texas, the sodium ions must be less than 45 percent of the total anions when the dissolved-solids concentration in the water is greater than 350 mg/L (Rio Grande Compact Commission, 1994). The water must also meet State of Colorado water-quality standards. The effect of the project on solute concentrations in the unconfined aquifer in the closed basin is probably not significant at this time (1993), however, because the project was not operating at full capacity prior to ground-water sampling.

Land Use

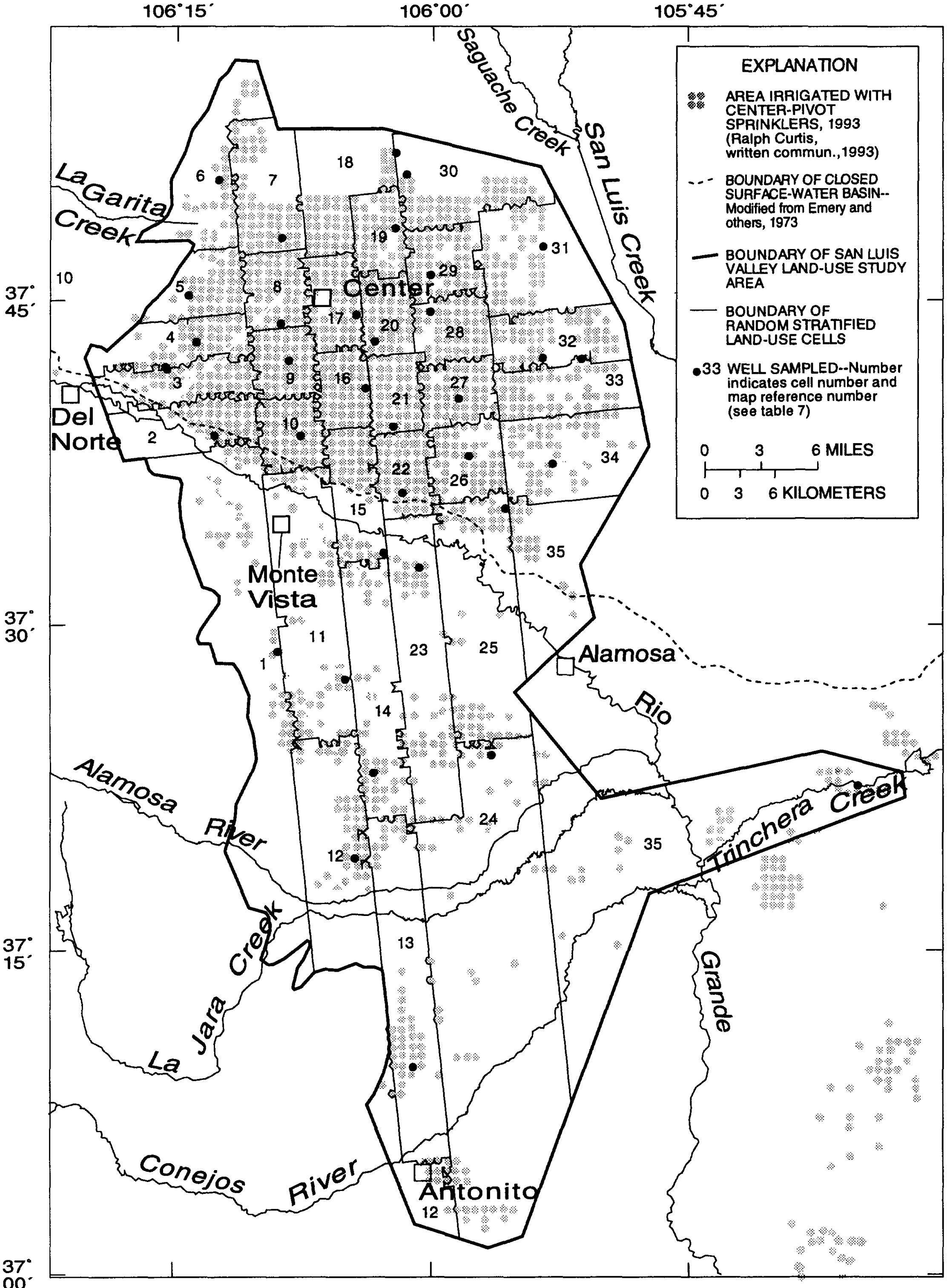
The dominant land use in the San Luis Valley is agriculture, and many changes in agricultural practices have taken place in the area since the late 1800's. These changes in agricultural practices include the sources of water used for irrigation, the location of irrigated areas, and how water has been applied to crops. The changes have affected the ground-water flow system in the valley (Hearne and Dewey, 1988) and probably the ground-water quality throughout the San Luis Valley. Hearne and Dewey (1988, p. 11) indicated five main changes in agricultural practices: "(1) Extensive diversion of surface water started about 1880; (2) development of confined ground water started about 1890; (3) a shift of irrigated areas from the center of the Alamosa Basin to the west was completed by about 1910; (4) ground-water withdrawals by large-capacity irrigation wells (greater than 300 gallons per minute) became significant about 1950; and (5) extensive irrigation by sprinkler systems started about 1970." However, beginning in the 1960's, some lands abandoned by 1910 were being reclaimed as productive farm land.

Siebenthal (1910, p. 19-20) indicated that by 1899 almost 300,000 acres were irrigated with water from the Rio Grande and tributaries in the San Luis Valley and that the water of the Rio Grande was greatly overappropriated. In 1887 the first artesian well was drilled (Powell, 1958, p. 26), and by 1904 about 3,200 artesian wells were in the valley, most of them small-diameter wells (3 inches or less). The number of artesian wells and the diameter of the wells increased steadily as the demand for additional and reliable supplies of irrigation, domestic, and stock water increased. Powell (1958, p. 27) indicated that by about 1950 about 7,500 wells were tapping the confined aquifer.

The favored method of irrigation prior to the use of sprinkler irrigation was referred to as "subbing." Subbing involved raising the water table by recharging the aquifer with diverted surface water or water from artesian wells to maintain the water table at a level at or near the root zone of the crops. The level of the water table was then regulated by a series of check drains (Powell, 1958, p. 45). The higher water levels caused waterlogging and alkali damage of soils in some of the eastern areas of the San Luis Valley by the early 1900's. This resulted in the development of agricultural lands west of these areas. Water levels rose 50 to 100 feet above predevelopment levels in these newly developed agricultural areas as the result of the infiltration of surface water applied for irrigation (Powell, 1958, p. 56).

After 1950 the number of large-capacity irrigation wells increased dramatically. After 1970 irrigation with center-pivot irrigation systems (center-pivot sprinklers) gained popularity. The center-pivot sprinklers generally are set up on a 1/4 section (160 acres), and the wells generally pump water from the unconfined aquifer. Most systems cover only about 130 acres because the corners of the 1/4 section are not irrigated with most overhead sprinklers, which move in a circle around a point in the center of the field. Hearne and Dewey (1988, p. 47) indicated that 710,000 acres were irrigated in 1980 in the area that includes most of the San Luis Valley. They reported that the mean annual volume of surface water diverted and ground water withdrawn for irrigation was 1,494,000 acre-feet from 1950 to 1979. By 1990 nearly 2,000 center-pivot sprinklers were being used in the San Luis Valley (Ralph Curtis, oral commun., 1993). In 1993 center-pivot sprinklers and flood irrigation were the two main methods used to irrigate crops in the San Luis Valley. The density of center-pivot sprinklers in the closed basin near Center is much greater than the density in the part of the San Luis Valley drained by the Rio Grande (fig. 3). In fact, near Center, little or no flood irrigation is done.

The main crops grown in the San Luis Valley are alfalfa, native hay, barley, wheat, potatoes, and other vegetables. Many of the farmers rotate barley or alfalfa and potatoes on their fields. Fertilizers and pesticides are applied to the fields by chemigation (fertilizers or pesticides are added to irrigation water and applied with irrigation water), aerial spraying, and land-based spraying. Eddy-Miller (1993) indicated that more fertilizers are applied to potatoes (170 pounds per acre) than to barley (55 pounds per acre). She also pointed out that the fertilizers usually are applied to barley only at the beginning of the season, whereas fertilizer applications for potatoes continue throughout the entire growing season. The amount of pesticides used in the San Luis Valley in 1989 (Bohmont, 1991) is presented in table 2. This information is based on tabulation of individual farmer questionnaires and is probably representative of 1993 pesticide use because the crop rotation scheme used by the farmers has not changed and negligible amounts of new land have been brought under irrigation since 1989. EPTC, sulfur, and 2,4-D are the pesticides used in the largest quantities in the San Luis Valley (table 2).



Base from U.S. Geological Survey digital data, 1:100,000 scale, various dates

Universal Transverse Mercator projection, zone 13

Figure 3.--Location of the area irrigated with center-pivot sprinklers, boundary of the San Luis Valley land-use study area, random stratified land-use cells, and wells sampled.

Table 2.--Summary of pesticide amounts used in the San Luis Valley in 1989

[From Bohmont, 1991. Bold type indicates pesticides analyzed for in samples]

Common name	Pounds active ingredient
2,4-D	87,600
Alachlor	140
Alicarb	8,500
Benfluralin	750
Bromoxynil	22,000
Captan	16,000
Carboxin	2,380
Chlorothalonil	49,000
Chlorpyrifos	5,850
Copper	16,000
DCPA	2,000
Dicamba	256
Diclofop	15,700
Diquat	2,200
Disulfoton	5,600
Diuron	18,000
EPTC	130,000
Endosulfan	3,990
Esfenvalerate	1,300
Fenvalerate	1,500
Glyphosate	1,100
Hexazinone	1,300
Imazamethabenz	6,090
Linuron	2,100
MCPA	6,010
Mancozeb	46,016
Maneb	42,416
Metalaxyl	2,290
Methamidophos	7,000
Methomyl	20
Metolachlor	12,000
Metribuzin	2,220
Oxyfluorfen	10
Parathion-ethyl	7,170
Parathion-methyl	3,700

Table 2.--Summary of pesticide amounts used in the San Luis Valley in 1989 --Concluded

Common name	Pounds active ingredient
Permethrin	1,410
Pronamide	1,800
Propiconazole	201
Sethoxydim	250
Streptomycin	7,200
Sulfur	110,000
TCMTB	159
Thiabendazole	4,300
Triadimefon	576
Triallate	10,300
Tribenuron	1
Thifensulfuron	1
Thiophanate-methyl	210
Triphenyltin hydroxide	4,300
Thiram	776

A high-altitude photograph taken in 1993 (fig. 4) shows that agriculture is the primary land use; however, some nonirrigated and residential land is interspersed with the agricultural lands. Most residential land is limited to individual homes, farm equipment storage yards, and potato warehouses on small parcels of land. Alamosa is the largest population center in the San Luis Valley, with a 1990 population of 7,579 (U.S. Department of Commerce, 1991). Monte Vista, Center, Del Norte, and Antonito are the other main population centers in the San Luis Valley (fig. 1).

METHODS

Various methods were used during the data-collection phase of this study to ensure that the data were unbiased and that the water samples represented the shallow ground-water quality in the vicinity of the monitor well. The following sections describe the procedures used to select the location of the monitor wells, the procedures used to install and sample the wells, the procedures used to analyze the samples, and the results of the quality assurance/quality control data. The procedures used during this study are based on the protocols developed for the NAWQA program (Koterba and others, 1995; Lapham and others, 1995).

Well Criteria and Site Selection

The following criteria were established to determine whether existing wells were suitable for use in this study: (1) well was perforated in only the upper 10 to 15 feet of the zone of saturation; (2) casing material and screens were PVC or stainless steel; (3) well was used only for monitoring; (4) well was not located in an area of known local contamination; and (5) well was located near land irrigated by center-pivot sprinklers. A review of existing well data indicated that new wells would need to be installed because no wells were available that met all the criteria.

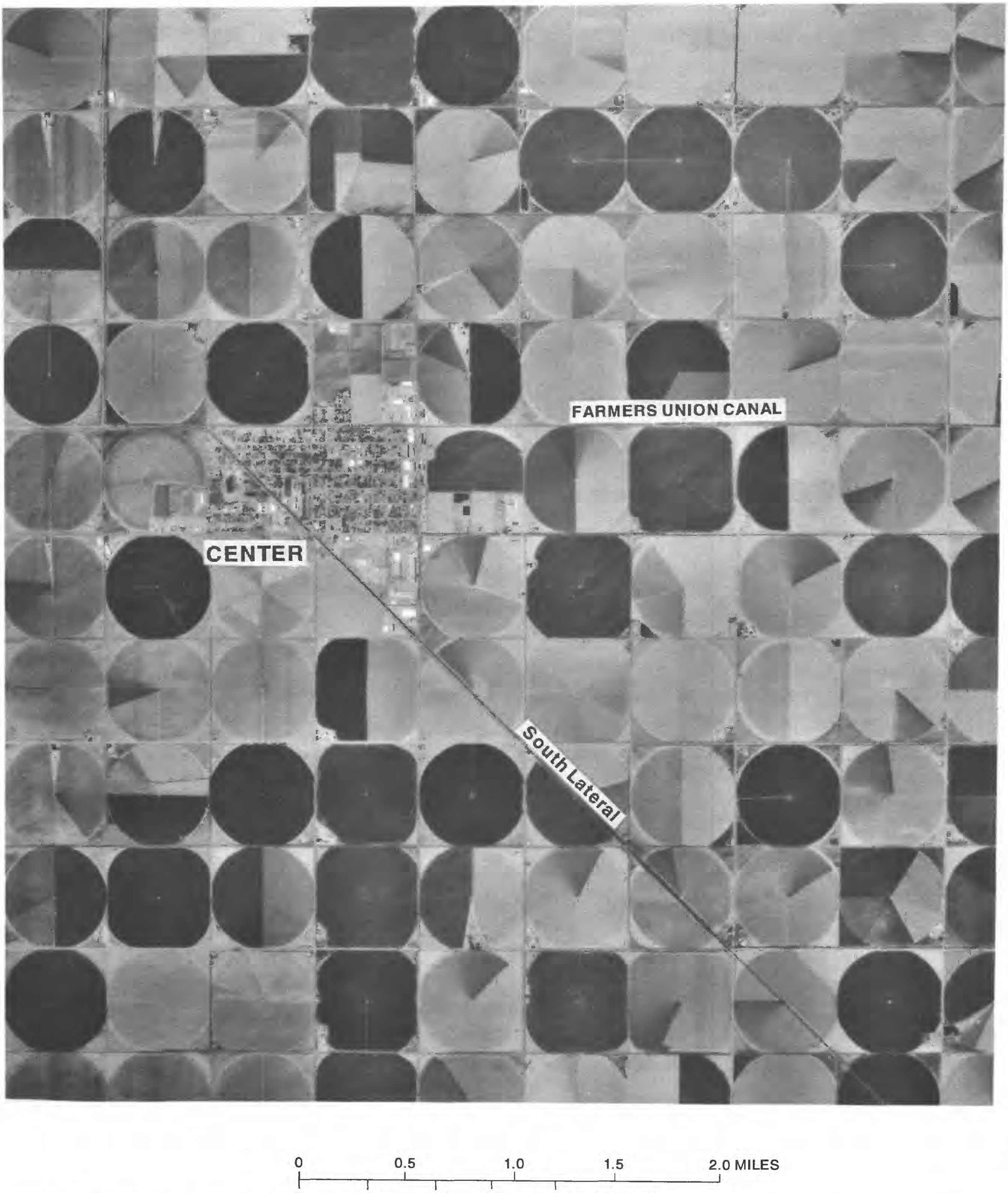


Figure 4.--Aerial photograph of typical irrigated area in the San Luis Valley land-use study area. Photograph taken June 6, 1993. (Photo NAPP 6674-203 provided by Earth Data Analysis Center.)

Well sites were selected using a computerized stratified random sampling within cells technique (Scott, 1990). The study area, which is the area of the San Luis Valley where depth to water is generally less than 25 feet (fig. 3), was stratified or grouped into either land irrigated with center-pivot sprinklers or other land. The land irrigated with center-pivot sprinklers was delineated using information obtained from the Rio Grande Water Conservation District (Ralph Curtis, written commun., 1993). The random sampling within cells program first defined a population of 10,160 equally spaced potential sites in the study area. The program then divided the study area into 35 cells, each with an equal area irrigated by center-pivot sprinklers (fig. 3). Each cell was numbered, and the well installed in each cell was given a map reference number that corresponds with the cell. A primary and three alternate sites were then randomly selected from the potential sites in each cell. The number of potential sites in each cell ranged from 10 to 39. Field personnel contacted land owners to obtain permission to install monitor wells on private property. If permission could not be obtained to locate a site within 600 feet of the primary site, the process was repeated at each alternate site until a site was located. The criteria used to determine an acceptable site were (1) land owner was willing to let the USGS install the well and maintain access for 10 years; (2) no utility lines were at the site; and (3) the site was easily accessible to the drilling rig. All wells were located adjacent to areas irrigated with center-pivot sprinklers. Most of the wells were located in the corners of irrigated 1/4 sections.

Monitor Well Installation

Thirty-five monitor wells were constructed in early August using a hollow stem auger that drilled an 8-inch hole. Wooden plugs were inserted in the open end of the bit and the holes were augured to a depth approximately 10 feet below the water table. The driller determined the location of the water table on the basis of drilling rate and examination of cuttings. The wells were constructed using 10 feet of well screen that was placed opposite the top 10 feet of the zone of saturation. Two-inch inside-diameter PVC casing and well screen (0.01-inch slot size) were removed from the protective plastic bags in which they were packed by the manufacturer, screwed together by field personnel, and lowered into the center of the hollow auger flights. All components of the well casing were handled by personnel wearing clean rubber gloves. The wooden plugs were popped out of the bottom of the bit using the assembled well casing, and the augers were pulled up out of the hole. The hole generally collapsed to the top of the water table; if it did not, packaged silica sand was added to fill the annular space to the water table. Bentonite pellets were added to create a 2- to 3-foot-thick seal above the water table and screens, and the hole was backfilled with drill cuttings to within 1 foot of land surface. A 5-inch-diameter by 3-foot-long steel well protector was installed over the PVC casing, and a concrete pad was installed at the site. The auger flights were then steam cleaned to prevent cross contamination between wells.

The wells were developed within 3 weeks after well installation using a PVC bailer and a pump. About 100 gallons of water were bailed from each well to remove sediment from the bottom of the well and to surge the wells. Each well was then pumped until the water discharging from the well was free of sediment.

Water Sampling

In August and September 1993, 35 monitor wells (fig. 3) were sampled for selected common constituents, nutrients, trace elements, radionuclides, volatile organic compounds (VOC's), and pesticides (table 3). Pesticides were analyzed using two different techniques and are grouped in table 3 to reflect the technique used for each particular pesticide. The wells were sampled 1 week or more after the wells were developed. A more detailed discussion of the procedures used to sample the wells is presented by Koterba and others (1995).

The wells were sampled using a 1.8-inch submersible pump that was lowered into the wells and plumbed to the sampling van using Teflon tubing. The wells were pumped to remove three casing volumes of water from the well prior to any field measurements. Field measurements included temperature, specific conductance, pH, dissolved oxygen, and turbidity; measurements were taken at 5-minute intervals until the chemistry of the discharge water stabilized. The stability criteria used were (1) less than 0.5-degree Celsius variation in temperature; (2) less than 10-percent variation in specific conductance; (3) less than 0.1-unit variation in pH; (4) less than 0.3-milligram-per-liter (mg/L) variation in dissolved oxygen; and (5) less than 5-turbidity-unit variation in turbidity. After the water met the stability criteria, it was diverted to the sampling chamber (a PVC frame enclosed in a plastic bag) located in the sampling van where all samples, with the exception of radon-222, were collected. Radon-222 samples were collected outside of the sampling van using a special collection unit (Koterba and others, 1995, p. 70). Pesticide samples were filtered using an aluminum filter plate and a 0.7-micron-pore-size baked glass filter. Inorganic samples were filtered using an acrylic filter plate and a 0.45-micron-pore-size filter. Samples for dissolved cations and trace elements were acidified to a pH less than 2 with trace-element grade nitric acid. Dissolved organic carbon (DOC) samples were filtered using a stainless steel filtering apparatus and a 0.45-micron-pore-size silver filter. All filtering, with the exception of DOC samples, was done inside the sampling chamber.

The pump and tubing were cleaned between sites by pumping and circulating a 0.1-percent solution of liquinox through the tubing for 10 minutes. About 3 gallons of deionized water was then pumped through the tubing. The pump and tubing were then dismantled and stored in clean plastic bags. The filter plates used for filtering pesticide samples were disassembled and washed with a 0.2-percent liquinox solution, rinsed with tap water, rinsed with deionized water, then rinsed with pesticide-grade methanol. After the filter plates had air dried, they were assembled without a filter, wrapped in aluminum foil, and stored in plastic bags. The acrylic filter plates used for inorganic samples were disassembled and washed with a 0.1-percent liquinox solution, rinsed with tap water, rinsed with deionized water, then reassembled without a filter. A 1.0-percent hydrochloric acid solution was then pumped through the filter units, followed by deionized water pumped through the units. The units were then drained and stored in clean plastic bags. The DOC filter unit was disassembled and rinsed with organic-free water, air dried, reassembled, then wrapped in aluminum foil.

National Water Quality Laboratory Methods

All samples were analyzed by the USGS National Water Quality Laboratory (NWQL). The methods used for the analysis of common ions and nutrients are outlined in Fishman (1993). Trace elements were analyzed by inductively coupled plasma/mass spectrometer techniques. Gross alpha and gross beta analytical methods are outlined by Thatcher and others (1977). Radon-222 was analyzed by liquid scintillation counting. Methods used for the analysis of VOC's are outlined by Rose and Shroeder (1995). Methods used for analysis of pesticides are outlined by Zaugg and others (1995) and Werner and others (1996). The NWQL has a quality assurance program in place, but the specifics of this program are not addressed in this report. Friedman and Erdmann (1982) and Pritt and Raese (1992) discussed the quality assurance program of the NWQL.

Table 3.--Constituents analyzed for and minimum reporting levels or method detection limit

[mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; *, minimum reporting level varies in some samples. Pesticides listed in group A extracted by C-18 solid phase extraction cartridge and analyzed by gas chromatography/mass spectrometric detector. Pesticides listed in group B extracted by Carbopak-B solid phase extraction cartridge and analyzed by high-performance liquid chromatography. Method detection limit is minimum concentration at which the pesticide can be identified, measured, and reported with 99-percent confidence that the concentration is greater than zero (Zaugg and others, 1995). All pesticides reported in micrograms per liter]

Common constituents

Constituent	Minimum reporting level (mg/L)
Calcium	0.02
Magnesium	0.01
Sodium	0.2
Potassium	0.1
Bicarbonate	0.1
Carbonate	0.1
Sulfate	0.1
Chloride	0.1
Fluoride	0.1
Bromide	0.01
Silica	0.01

Nutrients and dissolved organic carbon

Constituent	Minimum reporting level (mg/L)
Nitrite as nitrogen	0.01
Nitrite plus nitrate as nitrogen	0.05
Ammonia as nitrogen	0.015
Ammonia plus organic nitrogen as nitrogen	0.2
Phosphorus	0.01
Orthophosphorus	0.01
Dissolved organic carbon	0.1

Trace elements

Constituent	Minimum reporting level (µg/L)
Aluminum	1
Antimony*	1
Arsenic	1
Barium	1
Beryllium*	1
Cadmium*	1
Chromium*	1
Cobalt*	1
Copper	1
Iron	3
Lead*	1
Manganese	1
Molybdenum	1
Nickel	1
Selenium	1
Silver*	1
Uranium	1
Zinc	1

Radionuclides

Constituent	Minimum reporting level
Gross alpha dissolved as natural uranium	0.6 mg/L
Gross alpha dissolved as thorium-230	0.6 pCi/L
Gross beta as strontium-90/yttrium-90	0.6 pCi/L
Gross beta as cesium-137	0.6 pCi/L
Gross alpha suspended as natural uranium	0.6 mg/L
Gross alpha suspended as thorium-230	0.6 pCi/L
Gross beta suspended as strontium-90/yttrium-90	0.6 pCi/L
Gross beta suspended as cesium-137	0.6 pCi/L
Radon-222	24 pCi/L

Volatile organic compounds

Constituent	Minimum reporting level (µg/L)
Benzene	0.2
Bromobenzene	0.2
Bromochloromethane	0.2
Bromoform	0.2
Carbon tetrachloride	0.2
Chlorobenzene	0.2
Chlorodibromomethane	0.2
Chloroethane	0.2
Chloroform	0.2
Cis-1,2-dichloroethene	0.2
Cis-1,3-dichloropropene	0.2
Dibromochloropropane	1.0
1,2-Dibromoethane	0.2
Dibromomethane	0.2
1,3-Dichlorobenzene	0.2
1,4-Dichlorobenzene	0.2
Dichlorobromomethane	0.2
Dichlorodifluoromethane	0.2
1,1-Dichloroethane	0.2
1,2-Dichloroethane	0.2
1,1-Dichloroethylene	0.2
1,2-Dichloropropane	0.2
1,3-Dichloropropane	0.2
2,2-Dichloropropane	0.2
1,1-Dichloropropene	0.2
Ethylbenzene	0.2
Freon-113	0.2
Hexachlorobutadiene	0.2
Isopropylbenzene	0.2
Mesitylene	0.2
Methylbromide	0.2
Methylchloride	0.2
Methylene chloride	0.2
Methyltertbutylether (MTBE)	0.2
Napthalene	0.2
N-butylbenzene	0.2
N-propylbenzene	0.2
O-chlorobenzene	0.2
O-chlorotoluene	0.2
P-chlorotoluene	0.2
P-isopropyltoluene	0.2
Pseudocumene	0.2
Sec-butylbenzene	0.2
Styrene	0.2
Tertbutylbenzene	0.2
1,1,1,2-Tetrachloroethane	0.2
1,1,2,2-Tetrachloroethane	0.2
Tetrachloroethylene	0.2
Toluene	0.2
1,2-Transdichloroethene	0.2
Trans-1,3-dichloropropene	0.2
1,2,3-Trichlorobenzene	0.2
1,2,4-Trichlorobenzene	0.2
1,1,1-Trichloroethane	0.2
1,1,2-Trichloroethane	0.2
Trichloroethylene	0.2
Trichlorofluoromethane	0.2
1,2,3-Tricloropropane	0.2
Vinyl chloride	0.2
Xylene	0.2

Table 3.--Constituents analyzed for and minimum reporting levels or method detection limit--Concluded

Pesticides			
Group A		Group B	
Name	Method detection limit	Name	Method detection limit
Acetochlor	0.002	Acifluorfen	0.035
Alachlor	0.002	Aldicarb	0.016
Atrazine	0.001	Aldicarb sulfone	0.016
Benfluralin	0.002	Aldicarb sulfoxide	0.021
Alpha HCH	0.002	Amiben	0.011
Butylate	0.002	Bentazon	0.014
Carbaryl	0.003	Bromacil	0.035
Carbofuran	0.003	Bromoxynil	0.035
Chlorpyrifos	0.004	Carbaryl	0.008
Cyanazine	0.004	Carbofuran	0.028
DCPA	0.002	Chlorothalonil	0.035
p,p'-DDE	0.006	Clopyralid	0.050
Deethyl atrazine	0.002	2,4-D	0.035
Diazinon	0.002	Dacthal mono-acid	0.017
Dieldrin	0.001	2,4-DB	0.035
2,6-Diethylaniline	0.003	Dicamba	0.035
Dimethoate	0.024	Dichlobenil	0.020
Disulfoton	0.017	Dichlorprop	0.032
EPTC	0.002	Dinoseb	0.035
Ethalfluralin	0.004	Diuron	0.020
Ethoprop	0.003	Esfenvalerate	0.019
Fonofos	0.003	Fenuron	0.013
Lindane	0.004	Fluometuron	0.035
Linuron	0.002	3-Hydroxycarbofuran	0.014
Malathion	0.005	Linuron	0.018
Methyl azinphos	0.001	MCPA	0.050
Methyl parathion	0.006	MCPB	0.035
Metolachlor	0.002	Methiocarb	0.026
Metribuzin	0.004	Methomyl	0.017
Molinate	0.004	1-Naphthol	0.007
Napropamide	0.003	Neburon	0.015
Parathion	0.004	Norflurazon	0.024
Pebulate	0.004	Ocresol	0.035
Pendimethalin	0.004	Oryzalin	0.019
Permethrin	0.005	Oxamyl	0.018
Phorate	0.002	Picloram	0.050
Prometon	0.018	Propham	0.035
Pronamide	0.003	Propoxur	0.035
Propachlor	0.007	Silvex	0.021
Propargite	0.013	2,4,5-T	0.035
Propanil	0.004	Triclopyr	0.050
Simazine	0.005		
Tebuthiuron	0.010		
Terbacil	0.007		
Terbufos	0.013		
Thiobencarb	0.002		
Triallate	0.001		
Trifuralin	0.002		

The minimum reporting level (MRL) or the method detection limit (MDL) for a given constituent generally is determined based on the analytical methods used. The MRL is the lowest measured concentration of a constituent that may be reliably reported using a given analytical method (Timme, 1995, p. 92). The MRL is used when documentation for an analytical method is not available. The MRL is increased in samples where analytical interferences affect the analytical method. Due to unpredictable matrix effects on detection limits, the MRL is set somewhat higher than the MDL. The MDL's included in table 3 were defined and determined by personnel at the NWQL (Zaugg and others, 1995; Peter Rogerson, U.S. Geological Survey National Water Quality Laboratory, written commun., 1996). MDL's are the minimum concentration of a particular analyte that can be identified, measured, and reported with 99-percent confidence that the analyte concentration is greater than zero (Zaugg and others, 1995). When, as in some analyses, a particular pesticide was identified in a sample at a concentration below the MDL (confidence in concentration measured less than 99 percent), the concentration of the pesticide was reported as estimated.

Quality Assurance /Quality Control of Data

A quality assurance program ensured that the sampling procedures and characteristics of the water sampled (matrix bias or interferences) were not resulting in poor-quality data. Blank samples, duplicate samples, and spike samples were collected as part of the quality control used in this study. The results of the quality assurance program presented are a compilation of all quality assurance samples collected during the 1993 field season (table 4 and app. 1). The procedures used to collect samples were not changed during the field season, and the same personnel collected all samples so that any problems with data as the result of sampling procedures would be evident in the quality assurance data. Field blanks were collected and sent to the NWQL to ensure that chemical constituents were not being introduced to samples as the result of the sampling procedures used. Field blanks were collected by pumping inorganic- and organic-free water from a glass stand pipe with the submersible pump through the tubing and into the sampling chamber where the bottles were filled or the water was filtered and put into bottles. The blank samples were then processed (and acidified, if appropriate) and shipped to the NWQL using the same procedures as the ground-water samples.

Six field blanks were collected during the 1993 field season; most analytes were measured at concentrations less than the MDL or MRL (table 4), indicating that the sampling procedures did not introduce measurable concentrations of most constituents into the samples. Concentrations of constituents in the field blank samples that are greater than the MDL or MRL and in the same range as the concentrations measured in the ground-water samples indicate that concentrations of those constituents in the ground-water sample are questionable because it cannot be determined if the concentrations are caused by sampling procedures or if these constituents are actually present in ground water. Concentrations of constituents in the field blank samples at or near the MDL or MRL and much smaller than concentrations in the ground-water samples indicate that small differences in concentrations for a particular constituent in different ground-water samples may not be real but instead may be due to sampling and analytical procedures. Constituents analyzed for but not discussed below were not detected in any field blank samples; therefore, these constituents were not measurably affected by sampling procedures. However, the following constituents were affected by sampling procedures (table 4).

Table 4.--Constituents detected in blanks, range of concentrations in blank samples, and range of concentrations in shallow ground water

[MRL, minimum reporting level; MDL, method detection limit; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; E, estimated]

Constituent	MRL or MDL	Number of samples above MRL or MDL	Range of concentrations in blank samples	Range of concentrations in shallow ground water
Specific conductance (µS/cm)	1.0	6	2 - 3	93 - 2,750
Calcium (mg/L)	0.02	1	0.03	7.5 - 300
Alkalinity (mg/L as $CaCO_3$)	1.0	4	1.3 - 4.3	23 - 370
Chloride (mg/L)	0.1	2	0.1 - 0.3	0.3 - 160
Sulfate (mg/L)	0.1	5	0.2 - 0.4	2.4 - 1,100
Silica (mg/L as SiO_2)	0.01	6	0.02 - 0.2	14 - 64
Bromide (mg/L)	0.01	1	0.01	<0.01 - 0.9
Ammonia (mg/L as N)	0.015	6	0.01 - 0.03	<0.01 - 0.09
Phosphorus (mg/L as P)	0.01	2	0.01	0.01 - 0.27
Orthophosphorus (mg/L as P)	0.01	1	0.01	0.03 - 0.29
Aluminum (µg/L)	1	6	2 - 4	2 - 269
Cadmium (µg/L)	1	1	1	<1 - 4
Chromium (µg/L)	1	1	2	<1 - 5
Copper (µg/L)	1	2	1	<1 - 10
Iron (µg/L)	3	1	8	<3 - 67
Nickel (µg/L)	1	3	2	<1 - 10
Zinc (µg/L)	1	6	3 - 10	1 - 13
Dissolved organic carbon (mg/L)	0.1	4	0.1 - 0.3	0.2 - 6.5
Methylene chloride (µg/L)	0.2	4	0.4 - 4.0	<0.2
Benfluralin (µg/L)	0.009	1	E0.003	<0.009
Permethrin (µg/L)	0.016	1	E0.006	<0.016
Triallate (µg/L)	0.004	1	E0.001	<0.004

Calcium was detected in one field blank sample (0.03 mg/L), chloride in two field blank samples (0.1 and 0.3 mg/L), sulfate in five field blank samples (0.2 to 0.4 mg/L), and silica in all six field blank samples (0.02 to 0.2 mg/L). Bromide was detected in one sample at a concentration of 0.01 mg/L. Ammonia, at a concentration ranging from 0.01 to 0.03 mg/L as N, was detected in all six field blank samples. These ammonia concentrations are in the same range as those in about one-half of the native samples. Dissolved phosphorus was detected in two field blank samples at a concentration of 0.01 mg/L as P, and dissolved orthophosphorus was detected in one field blank sample at a concentration of 0.01 mg/L as P. Trace elements detected in the blank samples include aluminum in all six samples (2 to 4 micrograms per liter (µg/L)), cadmium in one sample (1 µg/L), chromium in one sample (2 µg/L), copper in two samples (1 µg/L), iron in one sample (8 µg/L), nickel in three samples (2 µg/L), and zinc in all six samples (3 to 10 µg/L). DOC was found in four field blank samples at concentrations ranging from 0.1 to 0.3 mg/L. Methylene chloride was detected in four of the field blank samples (0.4 to 4.0 µg/L), and the following pesticides were found once each in a blank sample: benfluralin (an estimated 0.003 µg/L), permethrin (an estimated 0.006 µg/L), and triallate (an estimated 0.001 µg/L). None of these organic compounds was detected in any of the ground-water samples. The results of the blank samples indicate that ammonia and zinc concentrations in ground-water samples need to be used with caution because sampling procedures could have resulted in the introduction of these constituents into the ground-water samples.

Duplicate samples were sent to the NWQL to determine precision for an individual sample site resulting from sampling procedures, matrix bias or interferences, or changes in the chemical composition of water withdrawn from the well during sampling. Comparison of the analytical results of the duplicate samples indicates good agreement (most values are within 10 percent) between measured concentrations (app. 1).

Surrogate compounds were added to all ground-water samples that were analyzed for pesticides, and spikes (field and laboratory) were added to selected ground-water samples analyzed for selected organic compounds to determine the precision and accuracy of the analyte recovery in the sample matrix and to determine the appropriateness of the analytical methods. Surrogate recoveries for the group A pesticide analyses ranged from 70 to 120 percent, indicating that the method was appropriate and that matrix effects were minimal for the surrogate compounds (app. 2). Surrogate recoveries for Group B pesticides ranged from 0 to 76 percent (app. 2). These relatively low surrogate recoveries are not necessarily indicative of poor performance of the method because the surrogates did not perform as expected (U.S. Geological Survey National Water-Quality Assessment/National Water Quality Laboratory Quality Assurance Committee, written commun., 1995). Median recoveries for spiked VOC's ranged from about 54 to 80 percent for 18 samples (6 laboratory spikes, 6 field spikes, and 6 field spike replicates) (app. 1). Median recoveries for spiked compounds for group A pesticides ranged from 60 to 140 percent with the exception of deethyl atrazine (median of 20 percent), dimethoate (median of 20 percent), permethrin (median of 20 percent), and propargite (median of 200 percent). NWQL personnel indicated that they generally have poor recoveries for the first three compounds and an interference resulting in large recoveries for the last compound (Steve Zaugg, oral commun., 1994). None of these compounds were found in the ground-water samples. Only two spike samples were collected for group B pesticides; these data are not presented because two spike samples do not provide enough data for evaluation. A summary of all spike data collected in the NAWQA program for group B pesticides is presented in an internal memo (U.S. Geological Survey National Water-Quality Assessment/National Water Quality Laboratory Quality Assurance Committee, written commun., 1995).

SHALLOW GROUND-WATER QUALITY

All ground-water quality data are presented in appendix 2 in the back of the report. In the following discussion, the shallow ground-water quality in the San Luis Valley is compared to National Primary Drinking Water Regulations (table 5).

National Primary Drinking Water Regulations have been established by the U.S. Environmental Protection Agency (EPA) for constituents that, if present in drinking water, may cause adverse human health effects (U.S. Environmental Protection Agency, 1993; 1994). For regulated constituents, National Primary Drinking Water Regulations specify either a Maximum Contaminant Level (MCL) or an action level that requires a treatment technique. MCL's are based on health standards (public water systems must comply with MCL's). Treatment techniques are established in lieu of MCL's when it is not economically or technically feasible to establish a quantifiable level of constituent for compliance purposes. Secondary maximum contaminant levels (SMCL's) are established for constituents that can adversely affect the odor or appearance of water and result in discontinuation of use of the water. SMCL's are generally set for aesthetic purposes and are not based on adverse health effects. Health advisories, also set by the EPA, are nonregulatory levels of constituents that can be used for guidance when no regulatory limits have been set. Health advisories are concentrations that would result in no known health effects and are estimated by making assumptions about body weight and amount of drinking water consumed per day. Lifetime health advisories used in this report assume a 70-year exposure period for a person weighing about 155 pounds and drinking about 2 quarts of water per day.

The MCL's and SMCL's are used in the following discussion as a frame of reference. None of the wells sampled is used for drinking water, and the water sampled from these wells is from the upper part of the unconfined aquifer in the area. Domestic and irrigation wells in the San Luis Valley probably tap deeper water in the aquifer than the monitor wells; therefore, comparing the quality of shallow ground water sampled with the quality of deeper ground water is not possible. The shallow ground water, however, could move deeper into the aquifer and affect the quality of the deeper ground water, which is used for domestic and irrigation purposes.

Properties and Common Constituents

The temperature of shallow ground water ranged from 8.7 to 17.1 °C (table 6). More than one-half of the samples had a temperature between 11.5 and 13.2 °C (table 6). The pH of shallow ground water ranged from 6.85 to 8.17 (table 6). These samples are acceptable based on the SMCL (table 5).

Specific conductance and dissolved solids of shallow ground water in the San Luis Valley have a wide range. Specific conductance (field) ranged from 93 to 2,750 microsiemens per centimeter at 25 °C (μS/cm), with a median or 50th percentile of 400 μS/cm. Dissolved-solids concentrations ranged from 75 to 1,960 mg/L (table 6). Specific conductance is a property measured in the field that is related to the dissolved solids in the water (a measurement generally performed in the laboratory). A plot of specific conductance and dissolved solids shows how these properties are related (fig. 5). The regression equation for the data can be used to estimate dissolved solids from specific conductance in shallow ground water in the area:

$$\text{dissolved solids (mg/L)} = (0.7234)\,(\text{specific conductance } (\mu\text{S/cm})) - 15.1 \qquad (1)$$

The R-squared value for this regression was 0.9932.

Table 5.--Drinking water standard or lifetime health advisory for constituents detected in shallow ground water, range of concentrations in shallow ground water, and percentage of shallow ground-water samples exceeding standards or lifetime health advisory

[F, final; <, less than; D, draft; P, proposed; pCi/L, picocuries per liter]

Constituent	Drinking water standard or lifetime health advisory[1] (milligrams per liter unless otherwise noted)	Status of standard	Range of concentrations in shallow ground water (milligrams per liter unless otherwise noted)	Percentage of shallow ground-water samples exceeding standard or lifetime health advisory
Aluminum	[2]0.05 - 0.2	F	0.002 - 0.269	[3]20
Arsenic	[4]0.05	F	<0.001 - 0.02	0
Barium	[4]2	F	0.013 - 0.174	0
Beryllium	[4]0.004	F	<0.001 - <0.002	0
Cadmium	[4]0.005	F	<0.001 - 0.004	0
Chloride	[2]250	F	0.3 - 160	0
Chromium	[4]0.1	F	<0.001 - 0.005	0
Copper	[5]1.3	F	<0.001 - 0.01	0
Dissolved solids	[2]500	F	75 - 1,960	26
Fluoride	[4]4	F	0.1 - 2.1	0
Gross alpha activity	[4]15 (pCi/L)	F	<0.5 - 100 pCi/L	23
Iron	[2]0.3	F	<0.003 - 0.067	0
Lead	[5]0.015	F	<0.001 - <0.002	0
Manganese	[2]0.05	F	<0.001 - 0.682	17
Methyltertbutylether	[6]0.02 - 0.2	D	0.0006	0
Metolachlor	[6]0.1	F	0.000072	0
Metribuzin	[6]0.1	F	0.000005 - 0.000017	0
Molybdenum	[6]0.04	D	<0.001 - 0.052	3
Nickel	[7]0.1	F	<0.001 - 0.01	0
Nitrite	[4]1	F	<0.01 - 0.03	0
Nitrite plus nitrate	[4]10	F	<0.1 - 58	31
pH	[2]6.5 - 8.5	F	6.9 - 8.2	0
Prometon	[6]0.1	F	0.00001	0
Radon-222	[4]300 (pCi/L)	P	700 - 1,900 pCi/L	100
Silver	[2]0.1	F	<0.001 - <0.002	0
Sulfate	[2]250	F	2.4 - 1,100	11
Uranium	[4]0.02	P	<0.001 - 0.084	17
Zinc	[2]5	F	0.001 - 0.013	0

[1] U.S. Environmental Protection Agency, 1993, 1994.

[2] Secondary maximum contaminant level.

[3] For 0.05 standard.

[4] Maximum contaminant level.

[5] Action level.

[6] Lifetime health advisory.

[7] Being remanded.

Table 6.--Statistical summary of selected data for shallow ground water in the San Luis Valley land-use study area

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than; alkalinity, gran (mg/L as $CaCO_3$), alkalinity in unfiltered sample as determined in the field by gran titration, in milligrams per liter as calcium carbonate; alkalinity, incremental (mg/L as $CaCO_3$), alkalinity in unfiltered sample as determined in the field by incremental titration, in milligrams per liter as calcium carbonate; ammonia + organic nitrogen (mg/L as N), dissolved ammonia and organic nitrogen as nitrogen; µg/L, micrograms per liter; µg/L as U-nat, micrograms per liter of equivalent natural uranium; pCi/L as Th-230, picocuries per liter as equivalent thorium-230; pCi/L as Sr-90/Y-90, picocuries per liter as equivalent strontium-90/yttrium-90; pCi/L as Cs-137, picocuries per liter as equivalent cesium-137, filtered sample]

Property or constituent	Total number of samples	Number of samples with concentration less than minimum reporting level	Mean	Standard deviation	Minimum	Maximum	Percentiles				
							10	25	50	75	90
Water temperature (degrees Celsius)	35	0	12.4	1.8	8.7	17.1	10	11.5	12	13.2	15
Specific conductance, field (µS/cm)	35	0	593.1	605.4	93	2,750	119	198	400	839	1,204
Dissolved solids (mg/L)	35	0	413.9	439.5	75	1,960	88	142	282	581	778
Oxygen, dissolved (mg/L)	35	0	3.4	2.7	0.1	8.0	0.1	0.5	3	5.6	6.7
pH, field (standard units)	35	0	7.5	0.3	6.85	8.17	7.05	7.37	7.43	7.66	7.8
Alkalinity, gran (mg/L as $CaCO_3$)	34	0	128.8	84.4	21.1	364	41.3	69.2	98.35	194	227
Alkalinity, incremental (mg/L as $CaCO_3$)	34	0	123.5	73.6	23	370	43	70	100	180	226
Bicarbonate, field (mg/L as HCO_3)	34	0	151	90	28	451	52	86	122	220	276
Bromide, dissolved (mg/L as Br)	35	11	0.1	0.2	<0.01	0.9	<0.01	<0.01	0.06	0.23	0.43
Calcium, dissolved (mg/L as Ca)	35	0	64.8	66.7	7.5	300	11	22	47	80	160
Chloride, dissolved (mg/L as Cl)	35	0	19.8	36.5	0.3	160	0.5	0.9	4.6	20	62
Fluoride, dissolved (mg/L as F)	35	0	0.4	0.5	0.1	2.1	0.1	0.2	0.3	0.5	1
Magnesium, dissolved (mg/L as Mg)	35	0	11.9	16.2	1.2	92	1.9	2.7	10	13	21
Potassium, dissolved (mg/L as K)	35	1	6.1	4.2	<0.1	19	1.4	3	5.2	9.5	11
Silica, dissolved (mg/L as SiO_2)	35	0	39.1	11.2	14	64	26	31	40	48	51

Table 6.--Statistical summary of selected data for shallow ground water in the San Luis Valley land-use study area--Continued

Property or constituent	Total number of samples	Number of samples with concentration less than minimum reporting level	Mean	Standard deviation	Minimum	Maximum	Percentiles				
							10	25	50	75	90
Sodium, dissolved (mg/L as Na)	35	0	42.8	53	2.5	200	3.9	8.7	19	72	140
Sulfate, dissolved (mg/L as SO_4)	35	0	120.6	216.9	2.4	1,100	4.6	7.1	45	140	260
Ammonia, dissolved (mg/L as N)	35	6	0.02	0.02	<0.01	0.09	<0.01	0.01	0.02	0.02	0.04
Ammonia + organic nitrogen (mg/L as N)	35	22	0.3	0.1	<0.2	0.7	<0.2	<0.2	<0.2	0.3	0.5
Carbon, organic, dissolved (mg/L as C)	35	0	2.4	1.6	0.2	6.5	0.9	1.4	1.7	3.1	5.4
Nitrite, dissolved (mg/L as N)	35	26	0.01	0.005	<0.01	0.03	<0.01	<0.01	<0.01	0.01	0.02
Nitrite plus nitrate, dissolved (mg/L as N)	35	2	8.5	12.3	<0.1	58	0.12	0.28	2.7	14	22
Phosphorus, dissolved (mg/L as P)	35	0	0.1	0.1	0.01	0.27	0.05	0.07	0.1	0.14	0.22
Orthophosphate, dissolved (mg/L as P)	35	0	0.1	0.1	0.03	0.29	0.05	0.07	0.1	0.15	0.23
Aluminum, dissolved (μg/L)	35	0	35.2	65	2	269	2	3	5	29	137
Antimony, dissolved (μg/L)	35	35	1	0.2	<1	<2	<1	<1	<1	<1	<1
Arsenic, dissolved (μg/L)	35	3	3.9	4.3	<1	20	1	2	3	4	9
Barium, dissolved (μg/L)	35	0	71.7	50.9	13	174	17	32	52	115	154
Beryllium, dissolved (μg/L)	35	35	1	0.2	<1	<2	<1	<1	<1	<1	<1
Cadmium, dissolved (μg/L)	35	34	1.1	0.5	<1	4	<1	<1	<1	<1	<1
Chromium, dissolved (μg/L)	35	29	1.3	1	<1	5	<1	<1	<1	<1	2
Cobalt, dissolved (μg/L)	35	33	1.1	0.2	<1	2	<1	<1	<1	<1	<1
Copper, dissolved (μg/L)	35	4	3	2.5	<1	10	<1	1	2	4	7.24
Iron, dissolved (μg/L as Fe)	35	3	13.1	14.4	<3	67	3	5	7	16	28
Lead, dissolved (μg/L)	35	35	1	0.2	<1	<2	<1	<1	<1	<1	<1
Manganese, dissolved (μg/L)	35	10	53.2	146.7	<1	682	<1	<1	2	27	119
Molybdenum, dissolved (μg/L)	35	8	6	10.1	<1	52	<1	1	2	6	14
Nickel, dissolved (μg/L)	35	10	2.5	1.9	<1	10	<1	<1	2	3	4
Selenium, dissolved (μg/L)	35	27	1.3	0.9	<1	5	<1	<1	<1	<1	2
Silver, dissolved (μg/L)	35	35	1	0.1	<1	<2	<1	<1	<1	<1	<1

Table 6.--Statistical summary of selected data for shallow ground water in the San Luis Valley land-use study area--Concluded

Property or constituent	Total number of samples	Number of samples with concentration less than minimum reporting level	Mean	Standard deviation	Minimum	Maximum	Percentiles				
							10	25	50	75	90
Uranium (µg/L)	35	12	10.4	19.7	<1	84	<1	<1	3	10	26
Zinc, dissolved (µg/L)	35	0	3.8	2.4	1	13	1	2	3	5	6
Gross alpha, dissolved (µg/L as U-nat)	35	6	15	28.7	<0.6	130	<0.6	0.9	3.5	15	32
Gross alpha, suspended (µg/L as U-nat)	35	30	0.8	0.6	<0.6	3.6	<0.6	<0.6	<0.6	<0.6	0.8
Gross alpha, dissolved (pCi/L as Th-230)	35	8	10.6	20.3	<0.6	89	<0.6	0.7	2.5	11	24
Gross alpha, suspended (pCi/L as Th-230)	35	31	0.8	0.7	<0.6	3.9	<0.6	<0.6	<0.6	<0.6	0.7
Gross beta, dissolved (pCi/L as Sr-90/Y-90)	35	0	8.4	8.7	1.3	35	2.3	3	5	11	15
Gross beta suspended (pCi/L as Sr-90/Y-90)	35	10	1.2	0.8	<0.6	3.7	<0.6	<0.6	0.8	1.5	2.6
Gross beta, dissolved (pCi/L as Cs-137)	35	0	11	11.6	1.6	48	2.8	3.4	6.7	14	20
Gross beta, suspended (pCi/L as Cs-137)	35	10	1.3	0.9	<0.6	3.8	<0.6	<0.6	0.9	1.6	2.8
Radon-222, total (pCi/L)	29	0	1,257.6	319.8	700	1,900	850	1,000	1,300	1,500	1,800

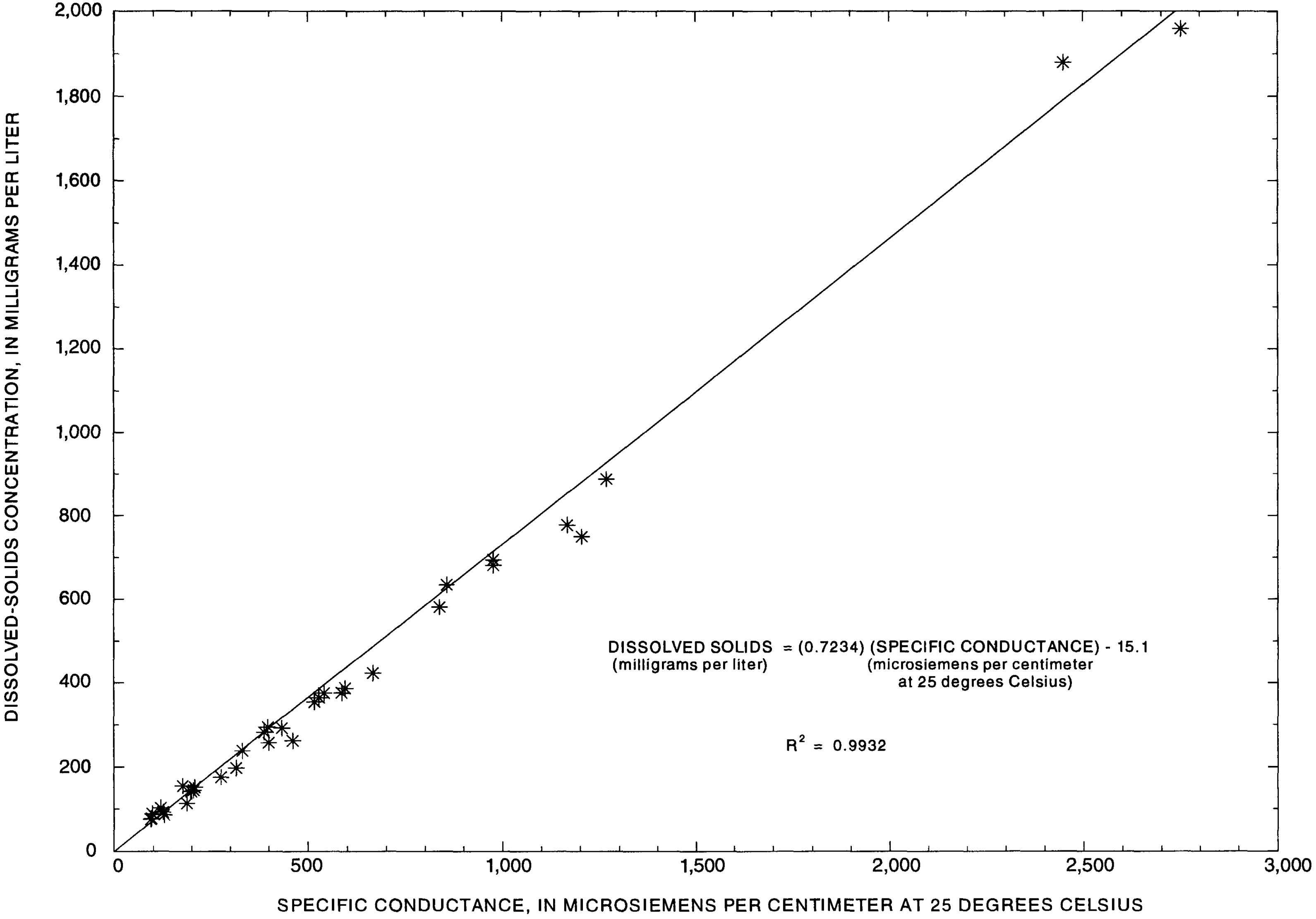


Figure 5.--Relation between specific conductance and dissolved-solids concentration in shallow ground water in the San Luis Valley land-use study area.

Although dissolved-solids concentration varies widely in small distances (fig. 6), a general increase in dissolved-solids concentration from west to east is indicated in the closed basin part of the study area. Water from 9 of the 35 wells sampled (26 percent) contained dissolved-solids concentrations greater than the SMCL of 500 mg/L (table 5).

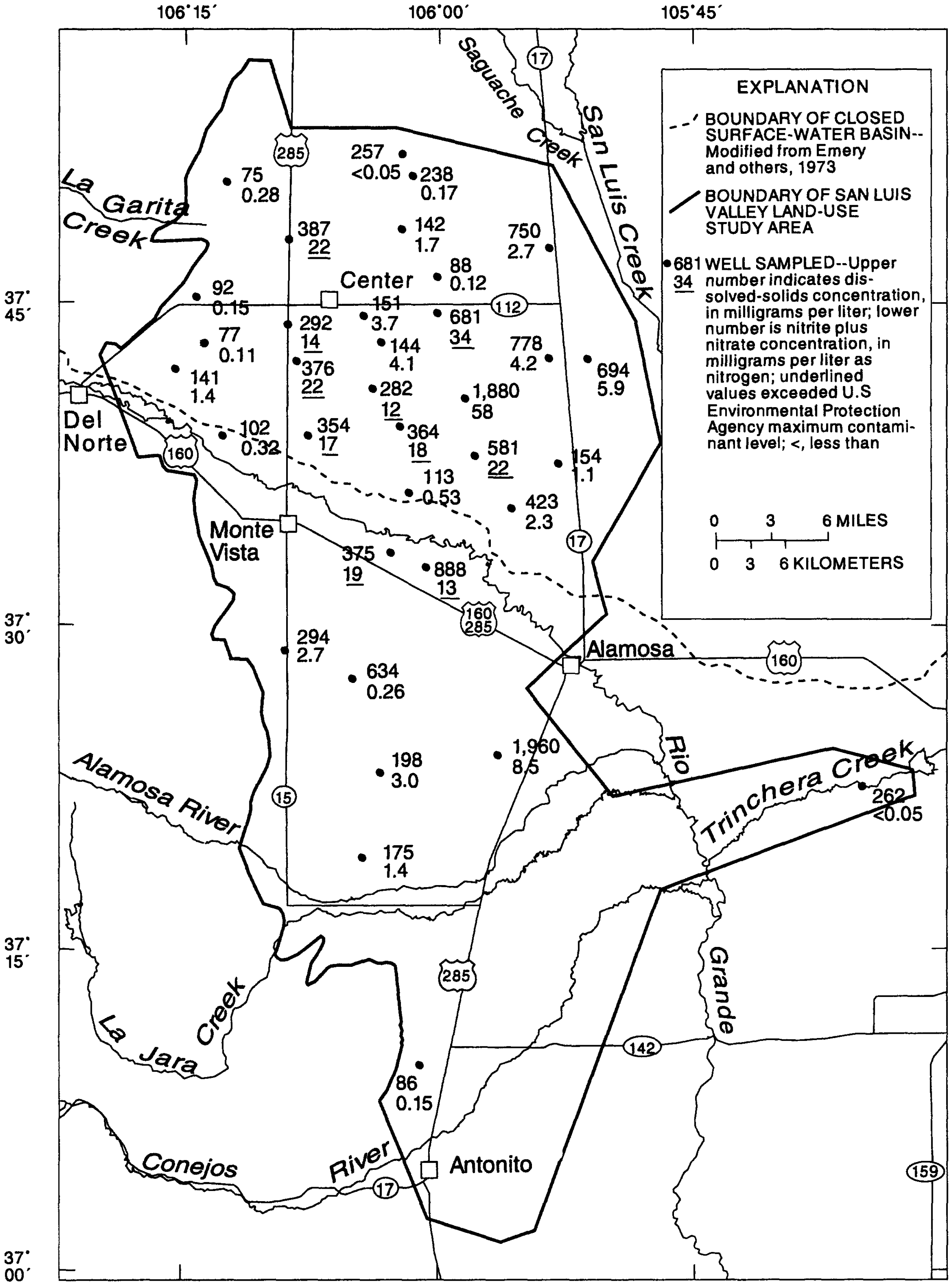
Among the cations, calcium had the largest median concentration and among the anions, bicarbonate had the largest median concentration in the water sampled (fig. 7). Calcium concentrations ranged from 7.5 to 300 mg/L, and bicarbonate concentrations ranged from 28 to 451 mg/L (table 6). Sodium, chloride, and sulfate concentrations also vary considerably in the shallow ground water. The EPA SMCL for both chloride and sulfate is 250 mg/L. None of the waters sampled exceed the SMCL for chloride, but water from 4 of the 35 wells sampled (11 percent) exceeded the SMCL for sulfate. Fluoride concentrations generally were less than 1.0 mg/L, which is well below the EPA MCL of 4 mg/L. Silica concentration ranged from 14 to 64 mg/L, and the median concentration was 40 mg/L (table 6). Bromide concentrations ranged from less than 0.01 to 0.9 mg/L, and the median concentration was 0.06 mg/L.

Nutrients, Dissolved Organic Carbon, and Dissolved Oxygen

Nitrite plus nitrate concentrations ranged from less than 0.1 to 58 mg/L as N and were the largest concentrations of nutrient species analyzed for. The nitrite concentrations were less than 0.01 mg/L as N in 26 of the 35 samples, indicating that nitrite plus nitrate concentrations generally are equal to the concentration of nitrate in the samples. Water from 11 of the wells sampled had nitrite plus nitrate concentrations greater than the EPA MCL of 10 mg/L as N (table 5). Nine of these 11 nitrite plus nitrate concentrations greater than 10 mg/L were in water from wells in the closed basin part of the study area (fig. 6). Nitrite, ammonia, and ammonia and organic nitrogen concentrations generally were below or slightly above the MRL's for these constituents (table 6). Phosphorus concentrations ranged from 0.01 to 0.27 mg/L as P, and the median concentration was 0.1 mg/L. DOC concentrations ranged from 0.2 to 6.5 mg/L, and the median concentration was 1.7 mg/L. Many of the DOC concentrations larger than the median were in water from wells in the northern and eastern parts of the study area in the closed basin. Dissolved-oxygen concentrations ranged from 0.1 to 8 mg/L, and the median concentration was 3 mg/L. Dissolved-oxygen concentrations generally were larger in water from wells in the western and southern parts of the study area in the closed basin.

Trace Elements

The term "trace elements" in this report refers to selected elements generally found in ground water at concentrations less than 1 mg/L. The trace elements analyzed for and the associated MRL for each element are listed in table 3. The concentrations of most trace elements analyzed for were at or below the MRL (table 6). Concentrations of aluminum, arsenic, barium, copper, iron, manganese, molybdenum, nickel, uranium, and zinc exceeded 5 μg/L in one or more samples. With the exception of aluminum, barium, iron, manganese, molybdenum, and uranium, concentrations of particular trace elements were less than 10 μg/L in 90 percent (90th percentile) of the samples (table 6). Aluminum, barium, and manganese concentrations were the only trace-element concentrations greater than 100 μg/L in one or more samples.



Base from U.S. Geological Survey digital data, 1:100,000 scale, various dates

Universal Transverse Mercator projection, zone 13

Figure 6.-Concentration of dissolved solids and nitrite plus nitrate in shallow ground water for 35 samples collected in the San Luis Valley land-use study area.

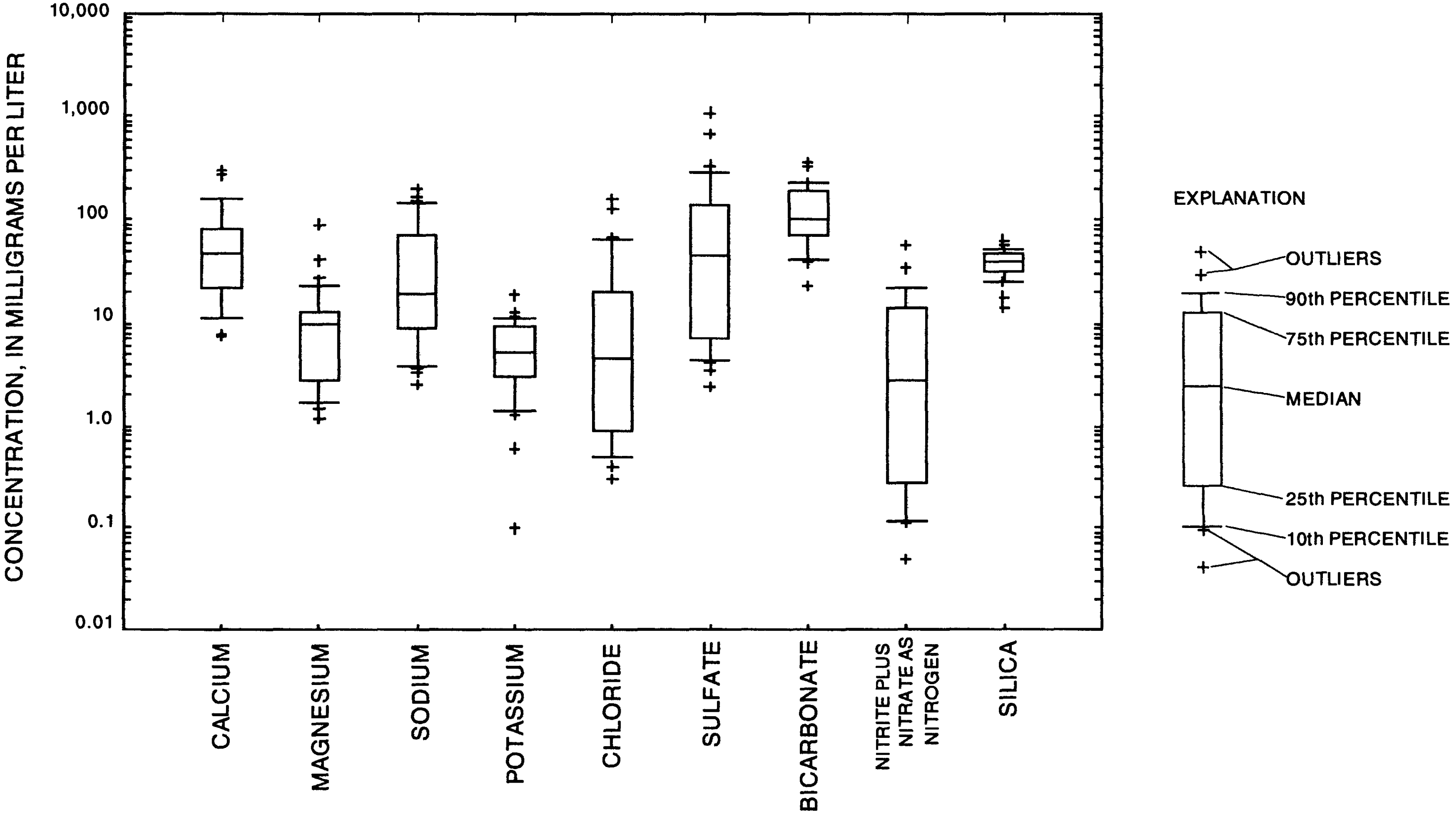


Figure 7.--Distributions of selected constituent concentrations in shallow ground water for 35 samples collected in the San Luis Valley land-use study area.

All trace-element concentrations measured were below the MCL's (table 5). The MCL for barium is 2 mg/L, which is about 10 times greater than the largest barium concentration measured. The MCL for beryllium is 4 µg/L (0.004 mg/L), but beryllium was not detected in any sample above the MRL. The MCL for cadmium is 5 µg/L, and it was detected only in one sample at a concentration of 4 µg/L. The MCL for chromium is 100 µg/L. Chromium was not detected above the MRL in 29 of the samples, and the largest concentration measured was 5 µg/L in 2 samples. The MCL for nickel is 100 µg/L, and the largest nickel concentration measured was 10 µg/L.

The EPA has established action levels of 1,300 µg/L for copper and 15 µg/L for lead. Action levels are concentrations that if exceeded require water treatment. Copper was detected in 31 samples at or above the MRL of 1.0 µg/L; however, the largest concentration measured was 10 µg/L, which is significantly below the action level. Lead was not found in any sample above the MRL.

SMCL's have been set for the following trace elements: iron, 300 µg/L; manganese, 50 µg/L; silver, 100 µg/L; and zinc, 5,000 µg/L (table 5). The largest iron concentration measured was 67 µg/L. Less than 20 percent of the manganese concentrations were greater than the SMCL. Silver was not detected in any sample. Zinc was detected in all samples at or above the MRL of 1 µg/L; however, the maximum concentration measured was 13 µg/L, which is significantly below the SMCL (table 5). Field blank samples indicate that zinc could have been introduced into the samples during sampling; therefore, zinc concentrations in the samples may not represent zinc concentrations in shallow ground water.

The EPA has proposed a maximum contaminant level of 20 µg/L for uranium. Five samples exceeded this proposed maximum contaminant level for uranium (table 6).

Radionuclides

Radiological analytes included dissolved and suspended gross alpha activity, dissolved and suspended gross beta activity, and radon-222. Dissolved gross alpha activity ranged from less than 0.6 to 130 µg/L as natural uranium, and dissolved gross beta activity ranged from 1.3 to 35.0 picocuries per liter (pCi/L) as strontium-90/yttrium-90 (Sr-90/Y-90) (table 6). Dissolved gross alpha and gross beta activities were less than 3.6 µg/L as natural uranium and 6 pCi/L as Sr-90/Y-90, respectively, in more than one-half of the samples. Thirty of the 35 samples did not have suspended gross alpha activities greater than the MRL, and 10 of the 35 samples had suspended gross beta activity less than the MRL (table 6). The largest suspended gross beta activity measured was 3.7 pCi/L as Sr-90/Y-90. Radon-222 concentrations ranged from 700 to 1,900 pCi/L (table 6).

The MCL for gross alpha activity is 15 pCi/L (U.S. Environmental Protection Agency, 1994). For gross alpha activity reported as equivalent uranium in µg/L, the mass to activity conversion factor used to determine gross alpha activity as uranium in pCi/L was 1.3 µg/L per pCi/L. Total gross alpha activity (dissolved plus suspended) exceeded the MCL in eight samples (table 5).

The MCL for gross beta activity is 4 millirem per year, which is a standard based on dose from ionizing radiation to the body (U.S. Environmental Protection Agency, 1994). It is not possible, using the data collected during this study, to compare gross beta standards with the measured gross beta activity in the ground-water samples.

The proposed MCL for radon-222 is 300 pCi/L (U.S. Environmental Protection Agency, 1994) and all of the shallow ground-water samples analyzed for radon exceeded the proposed MCL (table 5). The median radon-222 concentration was 1,300 pCi/L, indicating that most of the shallow ground water has radon-222 concentrations significantly above the proposed MCL. Radon gas, which causes lung cancer, can enter the home in ground water and is released to the air when the water is used for showering and other household uses (U.S. Environmental Protection Agency and others, 1992).

The MCL's for gross alpha and gross beta activity were set as screening devices for particular radionuclides. The regulations require that if public drinking water exceeds the MCL for gross alpha or gross beta, further sampling and analysis be done for specific radionuclides (U.S. Environmental Protection Agency, 1986). However, further sampling and analysis were not done as part of this study. The specific radionuclides that result in parts of the gross activities are discussed later in the Factors Affecting Shallow Ground-Water Quality section.

Volatile Organic Compounds

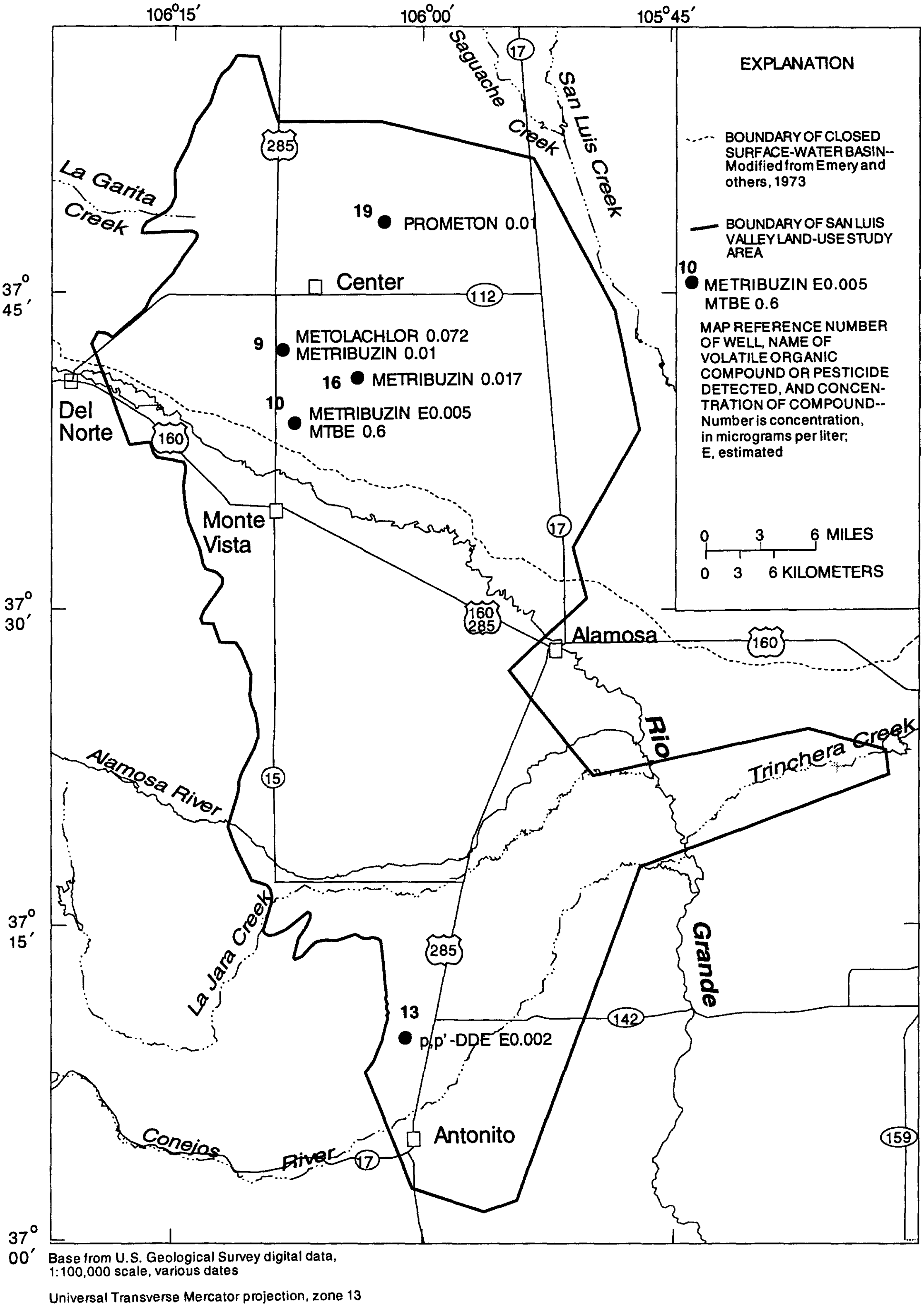
One VOC was detected in the 35 samples analyzed for the VOC's listed in table 3. Methyltertbutylether (MTBE), a gasoline additive, was detected at a concentration of 0.6 μg/L (fig. 8). This compound is very soluble in water and decomposes slowly compared with other gasoline additives (Squillace and others, 1995).

Pesticides

One or more pesticides were detected in water from 5 of the 35 wells sampled (fig. 8). All but one of these wells is in the closed basin of the San Luis Valley. Metribuzin was the most commonly detected pesticide (found in water from three wells). Metribuzin concentrations ranged from an estimated concentration of 0.005 to 0.017 μg/L. Prometon was detected in water from one well at a concentration of 0.01 μg/L. Metolachlor was detected in water from one well at a concentration of 0.072 μg/L. This was the largest concentration measured of any pesticide. The pesticide p,p'-DDE was detected at an estimated concentration of 0.002 μg/L in one sample. The EPA has not established MCL's for any of the pesticides detected in the San Luis Valley, but lifetime health advisory concentrations have been established for three of the pesticides. The health advisory concentration for metribuzin, prometon, and metolachlor is 100 μg/L (U.S. Environmental Protection Agency, 1996). The health advisory concentrations are significantly larger than the concentrations detected in shallow ground water in the San Luis Valley.

FACTORS AFFECTING SHALLOW GROUND-WATER QUALITY

Many factors and processes can affect water quality. Many of these factors and processes occur naturally; some, however, occur because of human-induced conditions. Infiltration of different compositions of water (recharge), evapotranspiration, precipitation of minerals, ion exchange, weathering and dissolution of minerals, and mixing with other waters are some of the most important factors and processes affecting the chemical composition of water in the unsaturated and saturated zones. In recharge areas, the composition of recharge water is one of the most important factors affecting ground-water quality, especially the quality of ground water in the upper part of the zone of saturation. The chemical composition of recharge water varies depending on its source. Recharge water can leach or dissolve material during infiltration through the unsaturated zone.



Base from U.S. Geological Survey digital data, 1:100,000 scale, various dates

Universal Transverse Mercator projection, zone 13

Figure 8.--Location and concentration of volatile organic compounds and pesticides detected in shallow ground water in the San Luis Valley land-use study area.

Elevated nitrate concentrations or synthetic organic compounds in ground water can indicate leaching of fertilizers or pesticides applied to the land surface. Although human-induced effects on ground-water quality are relatively easy to recognize in some cases, they are difficult to recognize in many cases. For example, leaching of minerals and solutes in the unsaturated zone in irrigated areas where irrigation efficiencies (volume of evapotranspiration divided by the sum of water applied and precipitation) are large can result in large concentrations of solutes in the shallow ground water. Infiltration of irrigation water that contains smaller concentrations of solutes than the ground water can result in an improvement in water quality in the aquifer. Conversely, human activities can also result in the contamination of shallow ground water by increasing concentrations of DOC, which can change the oxidation/reduction potential of the aquifer. Changes in the oxidation/reduction potential in the aquifer can then result in natural processes that affect nitrate or trace-element concentrations.

Determining specific factors or processes that affect shallow ground-water quality in an area can be difficult. In most cases the water quality in an area is the result of a combination of many factors and processes.

The ground-water and surface-water development in the San Luis Valley since 1880 has affected the ground-water flow system and water quality. Water quality can differ with depth in the aquifer. Wells sampled during this study were screened in the upper 10 feet of the zone of saturation, representing water quality in the upper part of the aquifer. Most previous investigators collected water-quality samples from wells screened deeper in the unconfined or confined aquifers. As a result, no water-quality data are available to compare with data collected during this study because the sampled intervals of the aquifer were not the same.

Ground water in the upper part of the aquifer is relatively young, and water quality is affected by land use in the area. Eddy-Miller (1993) determined that shallow ground-water monitor wells were useful in detecting nitrogen leaching from irrigated fields in the San Luis Valley. LeStrange (1995, p. 74) indicated that fertilizer applied to a field at the beginning of the growing season generally would not leach down to the ground water during that growing season. The fertilizer would, however, reach the water table and affect dissolved-nitrate concentrations by the following year.

The factors affecting water quality in the upper part of the aquifer are discussed by group of chemical constituents analyzed for. A brief discussion follows of the main factors or processes that could affect the chemical composition. The data are then discussed in terms of the factors or processes that are affecting the water quality in the upper part of the aquifer.

Properties and Common Constituents

Recharge to the unconfined aquifer occurs throughout most of the San Luis Valley; therefore, the composition of recharge water in a particular area would be one of the main factors affecting the concentrations of common constituents in the upper part of the aquifer. Although many processes can occur during infiltration of recharge water or in the aquifer, the chemical composition of the different sources of recharge water are starting compositions that can be used to compare to the common constituent concentrations in shallow ground water. Processes that can have an effect on common constituents are evapotranspiration, ion exchange, and precipitation and dissolution of minerals. Evapotranspiration causes increases in the concentrations of ions in recharge water or ground water. Ion exchange primarily affects the distribution of different cations in the water. Precipitation of minerals can cause decreases in the concentration of specific ions, and dissolution of minerals can cause increases in the concentration of specific ions. Evapotranspiration of soil water can cause the precipitation of minerals from the water. These minerals are retained in the soil zone. Some of these minerals, especially the more soluble ones, can be dissolved if additional recharge water contacts the minerals.

Dissolved-solids concentrations and specific conductance of shallow ground water in the San Luis Valley vary considerably. The largest dissolved-solids concentrations in shallow ground water are not limited to a specific area, indicating that specific processes are not causing increased dissolved-solids concentrations in isolated parts of the area (fig. 6). Dissolved-solids concentrations, however, generally increase from west to east in the closed basin part of the San Luis Valley.

A Durov plot of water compositions shows variations in the percentage of different anions and cations in each water sample (fig. 9). Variations in the percentages of the different ions could indicate different sources of recharge water or other processes that are affecting shallow ground-water quality. A Durov plot consists of two trilinear plots that represent concentrations as percentages of major cations or anions (in milliequivalents per liter) as a point in each respective trilinear diagram. Projections of the data points from the two trilinear plots to the central rectangular plot intersect to define a point that represents the major ion composition of each sample. Projections from this point to two adjacent rectangular plots are used to represent the water with respect to major ion composition and other constituents of the water composition.

The Durov plot indicates that the percentages of magnesium and chloride are relatively constant in the sampled ground water considering that dissolved-solids concentration of the water ranged from less than 100 to almost 2,000 mg/L (fig. 9). The percentage of calcium relative to the sum of calcium, sodium plus potassium, and magnesium ranges from about 20 to 80 and most samples contain 50 to 80 percent calcium. As the percentage of calcium decreases, the percentage of sodium plus potassium increases (fig. 9). Silica concentrations generally are greater than 40 mg/L in samples containing larger percentages of sodium plus potassium than calcium. The increase in the percentage of sodium plus potassium and larger silica concentrations could indicate that different sources of recharge water, ion exchange reactions, or dissolution of aquifer material are affecting the composition of these samples. The percentage of bicarbonate relative to the sum of bicarbonate, sulfate, and chloride ranges from about 10 to 100 percent. As the percentage of bicarbonate decreases, the percentage of sulfate increases (fig. 9).

The decrease in the percentage of bicarbonate with the associated increase in the percentage of sulfate is related to increases in dissolved-solids concentration (fig. 9). A plot of bicarbonate and dissolved sulfate concentration shows that as bicarbonate concentrations increase from about 50 to 200 mg/L, sulfate concentrations are generally less than 100 mg/L and do not seem to increase (fig. 10). Most of the samples that contain bicarbonate concentrations greater than 200 mg/L have sulfate concentrations greater than 100 mg/L. Six samples have sulfate concentrations greater than 200 mg/L (fig. 10). The reason that these samples have relatively large sulfate concentrations compared to bicarbonate concentrations is not known. Precipitation of calcite could limit the bicarbonate concentrations in the shallow ground water, whereas sulfate concentrations may not be limited by mineral precipitation.

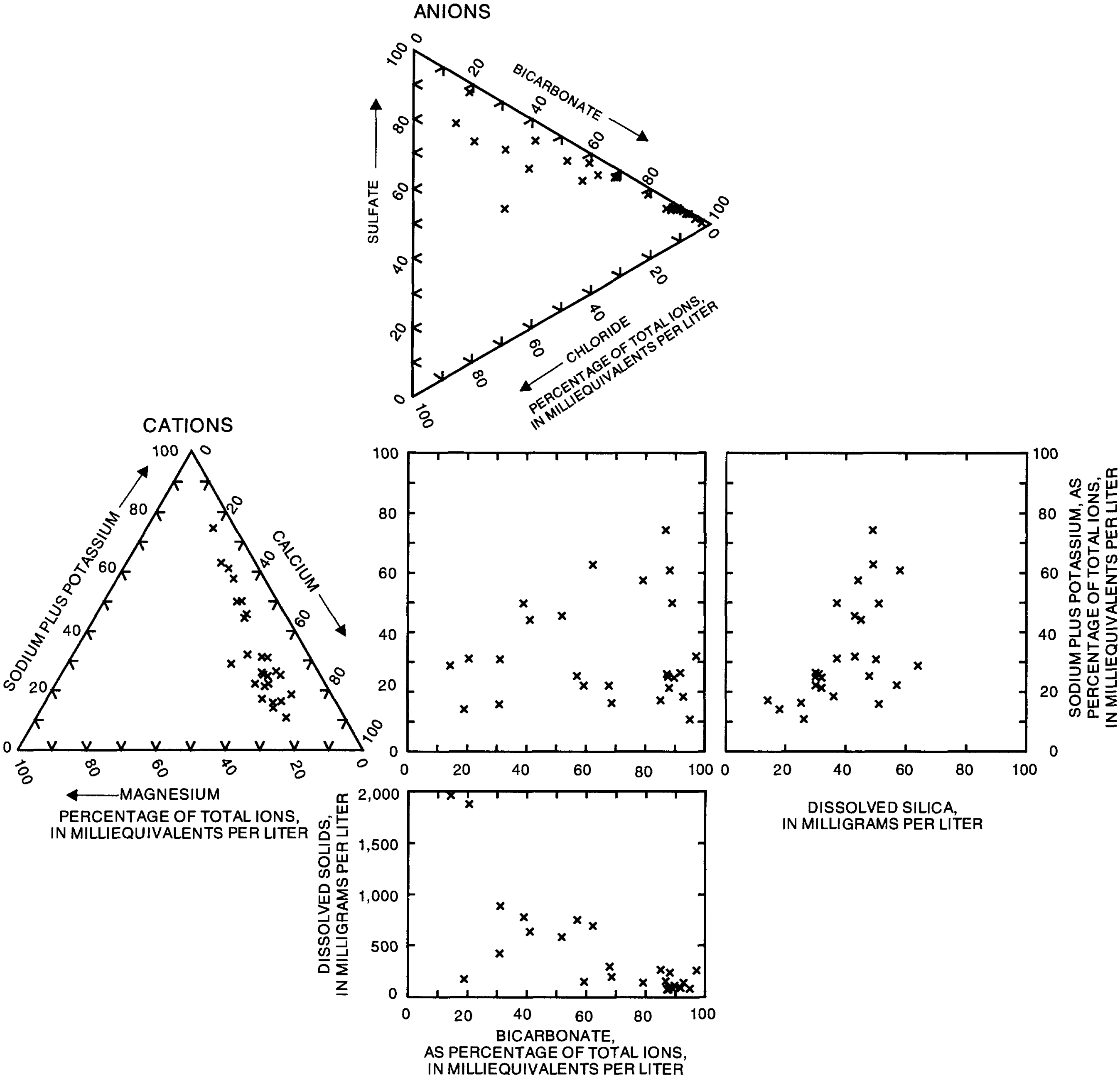


Figure 9.--Durov plot of shallow ground-water compositions in the San Luis Valley land-use study area.

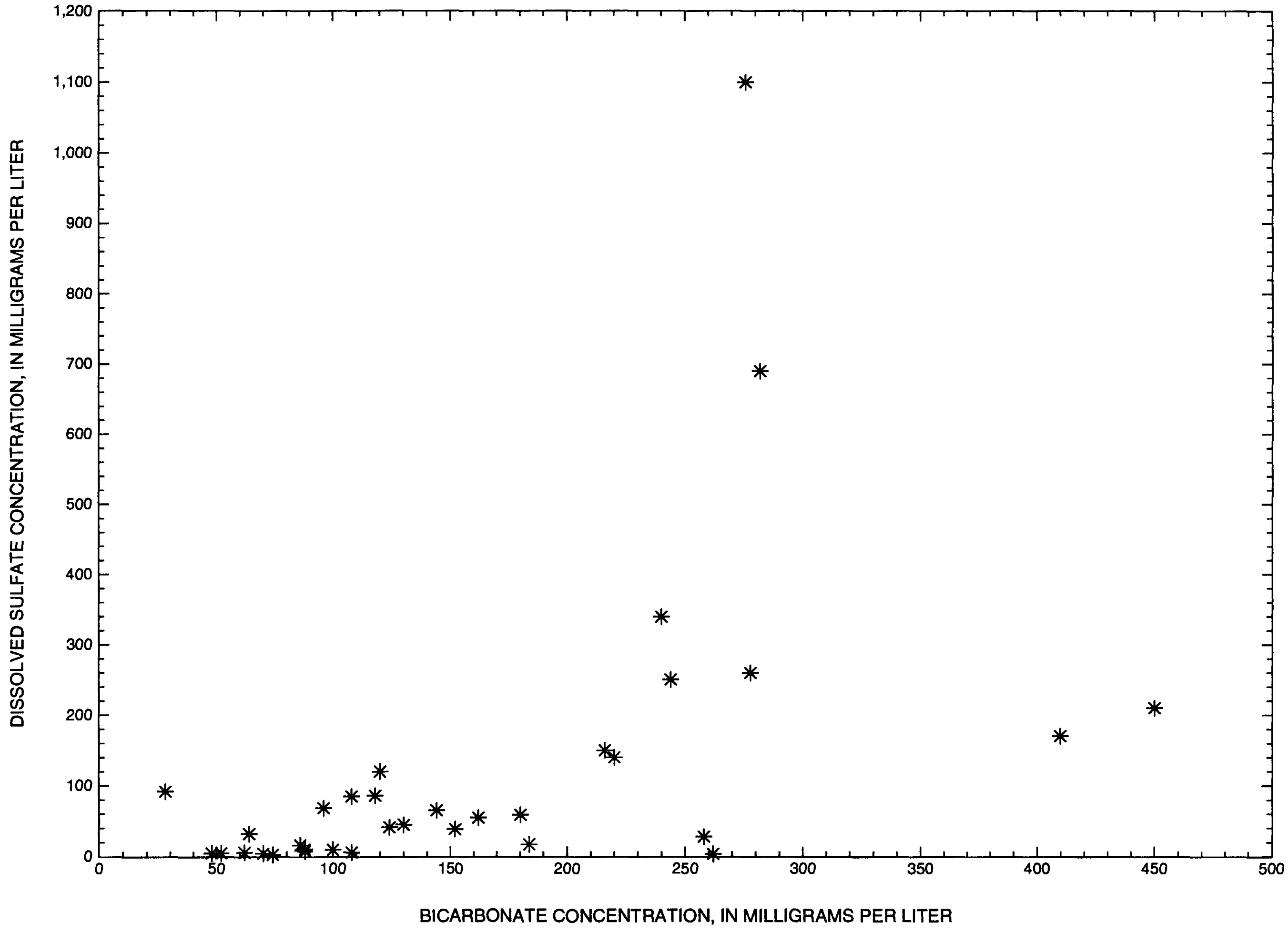


Figure 10.--Relation between bicarbonate and dissolved sulfate concentrations in shallow ground water in the San Luis Valley land-use study area.

Saturation indexes for selected minerals were calculated for all samples (table 7) using a computer program by Parkhurst and others (1980). The saturation index is the log of the ion activity product, which is a function of the concentration of individual ions in the sample, divided by the equilibrium constant, which is a characteristic of the particular mineral. A negative saturation index indicates that the mineral would tend to dissolve in the solution (undersaturated) and a positive saturation index indicates the mineral would tend to precipitate from the solution (supersaturated). The saturation index for calcite generally increased with increasing bicarbonate concentration (fig. 11). Many of the samples with the largest bicarbonate concentrations were supersaturated with respect to calcite, indicating that calcite tends to precipitate. The ground-water samples containing small bicarbonate concentrations were undersaturated with respect to calcite, indicating that calcite tends to dissolve in this ground water (fig. 11).

In the unconfined aquifer in the San Luis Valley, the main sources of recharge water are inflow of ground water from adjacent aquifers, infiltration of precipitation, infiltration of surface water, and infiltration of irrigation water (net irrigation recharge). The chemical composition of the water sampled in this study is probably most affected by the last three sources. The chemical composition of precipitation at several sites and surface water in several of the main rivers is known. The chemical composition of net irrigation recharge is more difficult to determine because of the different sources of irrigation water (surface water, ground water from the confined aquifer, and ground water from the unconfined aquifer). The chemical composition of net irrigation water was not estimated because of the expected large range in composition. Two of the main sources of recharge for both the confined and unconfined aquifers are precipitation and surface water; therefore, the chemical composition of ground water in the confined and unconfined aquifers that is used for irrigation could resemble the chemical composition of precipitation or surface water.

The chemical composition of precipitation, surface water, and shallow ground water and evaporation trends of precipitation and surface water were compared to determine whether the shallow ground-water quality is similar to the water quality of these two important sources of recharge. Because there is such a large range in the concentration of solutes in shallow ground water, this comparison was done at two scales. First, the chemical composition of all ground-water samples were compared to precipitation, surface-water, and evaporation trends to determine the overall similarities of the selected sources of recharge and the ground-water samples. Ground-water samples containing chloride concentrations less than 10 mg/L were then used in another comparison to examine the similarities of the samples that have lower concentrations of solutes.

Two different chemical compositions of precipitation were used in the comparisons. A median of the annual average precipitation weighted concentration of selected constituents in precipitation at Alamosa for 1980 to 1989 is presented in table 8 (National Atmospheric Deposition Program (NRSP-3)/National Trends Network, 1992). Average concentrations of selected constituents in 2-week composite samples of bulk deposition collected at Monte Vista from May 1982 to May 1983 also are included in table 8 (data from Lewis and others, 1984). Precipitation chemistry represents analysis of rain and snow only, whereas bulk deposition chemistry includes rain and snow plus the dust that falls into the collector and dissolves in the rain and snow during the sampling period. The concentration of individual ions is greater in bulk deposition than in precipitation because of the dissolution of some of the atmospheric dust trapped in the collector.

Table 7.--Dissolved solids, total inorganic carbon, and saturation index for selected minerals in shallow ground water in the San Luis Valley land-use study area

Map reference number (fig. 3)	Dissolved solids (milligrams per liter)	Total inorganic carbon (millimoles per liter)	Saturation index				
			Calcite	Barite	Fluorite	Chalcedony	Amorphous silica
1	294	3.16	-0.91	-5.75	-2.36	0.74	-0.15
2	102	4.52	-1.50	-4.94	-2.83	0.38	-0.49
3	141	1.96	-1.05	-5.13	-3.13	0.47	-0.41
4	77	7.74	-1.43	-2.29	-2.85	0.41	-0.48
5	92	1.12	-0.34	-1.25	-2.12	0.40	-0.48
6	75	1.29	-1.64	-3.78	-2.86	0.42	-0.47
7	387	2.51	-0.31	-1.18	-2.23	0.54	-0.35
8	292	2.18	-0.10	0.28	-1.91	0.45	-0.45
9	376	3.06	0.11	0.43	-2.17	0.45	-0.44
10	354	2.02	-0.80	-3.60	-2.77	0.39	-0.50
11	634	4.02	0.22	0.99	-1.46	0.57	-0.31
12	175	4.15	-1.03	0.17	-2.13	0.18	-0.70
13	86	1.30	-0.97	-2.51	-3.29	0.31	-0.57
14	198	1.94	-0.48	-0.88	-2.03	0.31	-0.57
15	375	1.57	-0.49	-0.65	-1.79	0.59	-0.30
16	282	1.47	-0.48	0.21	-1.77	0.52	-0.36
17	151	1.03	-0.46	-0.20	-2.63	0.37	-0.51
18	257	2.36	-0.60	-5.47	-1.58	0.59	-0.30
19	142	1.40	-0.71	-0.48	-1.46	0.55	-0.33
20	144	1.51	-0.89	-2.15	-2.58	0.42	-0.45

Table 7.--Dissolved solids, total inorganic carbon, and saturation index for selected minerals in shallow ground water in the San Luis Valley land-use study area--Concluded

Map reference number (fig. 3)	Dissolved solids (milligrams per liter)	Total inorganic carbon (millimoles per liter)	Saturation index				
			Calcite	Barite	Fluorite	Chalcedony	Amorphous silica
21	364	2.11	-0.32	-0.07	-1.90	0.56	-0.32
22	113	1.50	-0.86	-1.61	-2.61	0.42	-0.46
23	888	1.89	-0.12	-0.39	-1.29	0.67	-0.23
24	1,960	2.82	0.30	0.57	-1.17	0.74	-0.15
25	423	1.76	-0.17	0.68	-2.73	0.65	-0.24
26	581	3.02	-0.15	-0.13	-2.82	0.56	-0.32
27	1,880	1.04	-0.55	-2.05	-2.38	0.52	-0.37
28	681	2.87	-0.14	0.08	-1.82	0.60	-0.29
29	88	8.27	-1.20	-1.26	-3.09	0.43	-0.43
30	238	3.13	-0.37	-0.32	-0.63	0.68	-0.20
31	750	6.63	0.41	0.44	-1.96	0.61	-0.27
32	778	4.54	0.24	0.53	-0.90	0.64	-0.24
33	694	6.8	0.52	0.28	-1.04	0.45	-0.39
34	154	1.63	-0.86	-0.94	-1.68	0.60	-0.28
35	262	4.41	-0.0013	-0.70	-0.38	0.08	-0.81

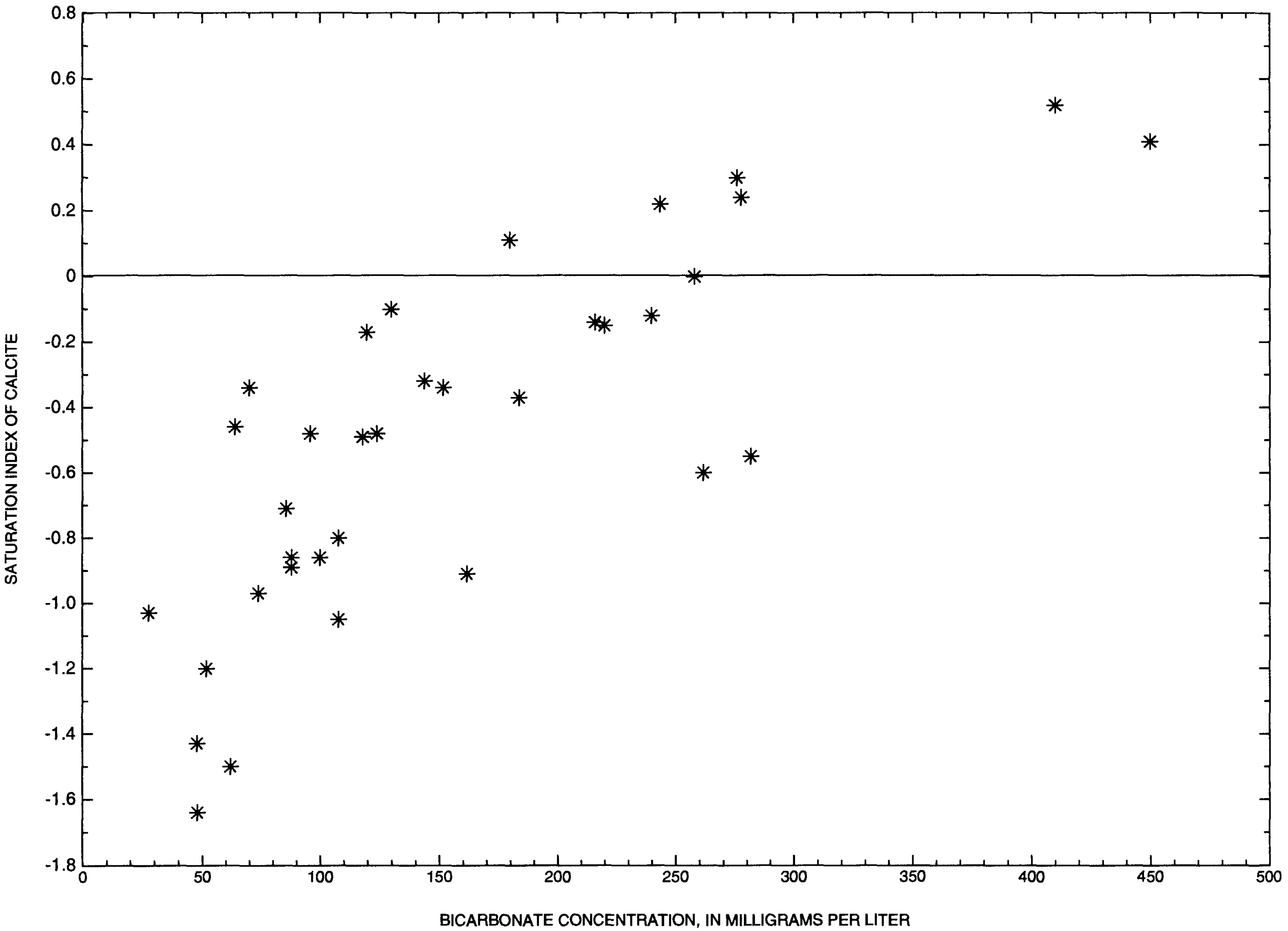


Figure 11.--Relation between bicarbonate concentration and saturation index of calcite in shallow ground water in the San Luis Valley land-use study area.

Table 8.--Median annual average precipitation weighted concentrations of selected constituents in precipitation at Alamosa, average concentrations of selected constituents in 2-week composite samples of bulk deposition at Monte Vista, median concentrations of selected constituents in Rio Grande at Del Norte water, and median concentrations of selected constituents in Conejos River near Lasauses water

[All concentrations in milligrams per liter; --, no data]

Constituent	Precipitation at Alamosa[1]	Bulk deposition at Monte Vista[2]	Rio Grande at Del Norte[3]	Conejos River near Lasauses[3]
Calcium	0.335	1.38	11.0	15.0
Magnesium	0.033	0.20	1.7	2.7
Sodium	0.191	1.00	3.9	5.3
Potassium	0.042	0.56	1.65	2.3
Chloride	0.145	0.92	0.8	1.0
Sulfate	1.150	3.30	6.05	5.7
Silica	--	--	23.0	29.0

[1] National Atmospheric Deposition Program (NRSP-3)/National Trends Network, 1992.

[2] Lewis and others, 1984.

[3] Ugland and others, 1994, 1995; unpublished data from U.S. Geological Survey files, Albuquerque, New Mexico.

Median concentrations of selected constituents in water samples from the Rio Grande at Del Norte and from the Conejos River near Lasauses from May 1993 to June 1995 are also presented in table 8 (Ugland and others, 1994, 1995; unpublished data from files of the U.S. Geological Survey, Albuquerque, New Mexico). Although the chemical composition of surface water varies throughout the year, these median concentrations were used to represent the composition of surface water that is diverted from these streams and could infiltrate and recharge the shallow aquifer.

Evaporation trends of the selected sources of recharge water, precipitation, bulk deposition, Rio Grande at Del Norte water, and Conejos River near Lasauses water can be compared to the chemical composition of shallow ground water (fig. 12). Evaporation trends are based on the ratio of chloride to sulfate, sodium, or calcium ions; processes or chemical reactions that can add or remove ions from the water were assumed not to occur during evaporation. Dissolved chloride concentration was plotted as the independent variable because the chloride ion is least affected by processes or chemical reactions. Significant differences between shallow ground-water composition and evaporation trends indicate that processes other than evapotranspiration, such as chemical reactions, are affecting the composition of shallow ground water.

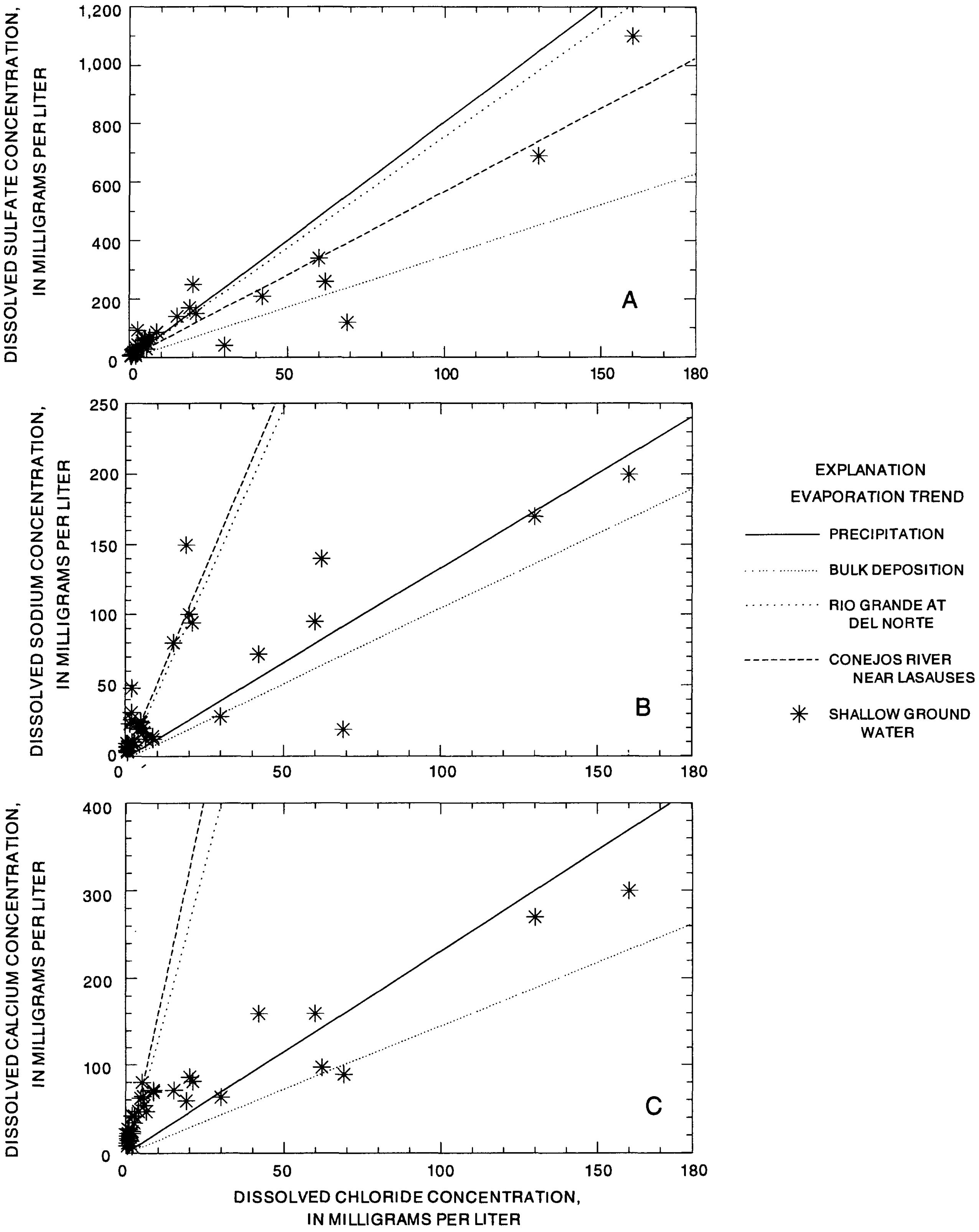


Figure 12.--Relations between (A) dissolved chloride and sulfate concentrations, (B) dissolved chloride and sodium concentrations, and (C) dissolved chloride and calcium concentrations in shallow ground water in the San Luis Valley land-use study area.

The chloride and sulfate plot (fig. 12A) shows that most shallow ground-water samples plot along or between the evaporation trends of the selected sources of recharge water, indicating that it is not possible to determine a unique source of ground-water recharge on the basis of chloride and sulfate concentrations. The ground water could be a mixture of precipitation and surface water that has been concentrated by evaporation. Two samples have excess chloride relative to sulfate when compared to the selected sources of recharge water (samples plot below bulk deposition evaporation trend) (fig. 12A). These two samples probably are affected by processes that add chloride to or remove sulfate from the water.

The chloride and sodium plot shows that the slopes of the evaporation trend for precipitation and bulk deposition are similar, but are much different from the slope of the evaporation trends for surface water (fig. 12B). The steeper slope of the evaporation trend for surface water indicates that surface water has a larger sodium to chloride ratio than precipitation or bulk deposition. Some ground-water samples plot along the precipitation evaporation trend and some plot along the surface-water evaporation trend, possibly indicating different sources of recharge water for the different ground-water samples. Ground-water samples with chloride concentrations greater than 30 mg/L plot along the precipitation evaporation trend, and samples with chloride concentrations between 10 and 30 mg/L plot along the surface-water evaporation trend.

The chloride and calcium plot also shows that ground-water samples with chloride greater than 30 mg/L generally plot along the precipitation evaporation trend (fig. 12C). The samples with chloride concentration between 10 and 30 mg/L plot between the evaporation trends of surface water and precipitation.

On the basis of the chloride-sodium plot and the chloride-calcium plot, the ground-water samples containing chloride concentrations greater than 30 mg/L are similar in composition to precipitation that has been concentrated by evaporation. Therefore, precipitation could be the main source of ground-water recharge in the area near the wells where these samples were collected. To confirm this, the other possible sources of recharge water, such as ground water from the confined and unconfined aquifer, would need to be compared to these shallow ground-water compositions and be ruled out as important sources.

Plots of chloride and sulfate, sodium, and calcium concentrations that include only those ground-water samples with chloride concentrations less than 10 mg/L were used to compare the more dilute ground water to selected sources of recharge. The chloride and sulfate plot (fig. 13A) shows that many ground-water samples have chloride and sulfate concentrations less than or equal to the chloride and sulfate concentrations in surface water, more chloride and sulfate than precipitation, and more sulfate than bulk deposition (fig. 13A). Several ground-water samples plot on a slope similar to the evaporation trends of precipitation and surface water, but contain more sulfate relative to chloride, thus they plot above the evaporation trends of the selected sources of recharge water. This indicates that a process occurs as the water is infiltrating and evaporating that results in the addition of sulfate to the water.

One source of sulfate to these ground-water samples could be the sulfur used as a pesticide in the area. Approximately 110,000 pounds of sulfur were applied in 1989 in the San Luis Valley (table 1). Dissolution of sulfur in recharge water could account for the additional sulfate in shallow ground water.

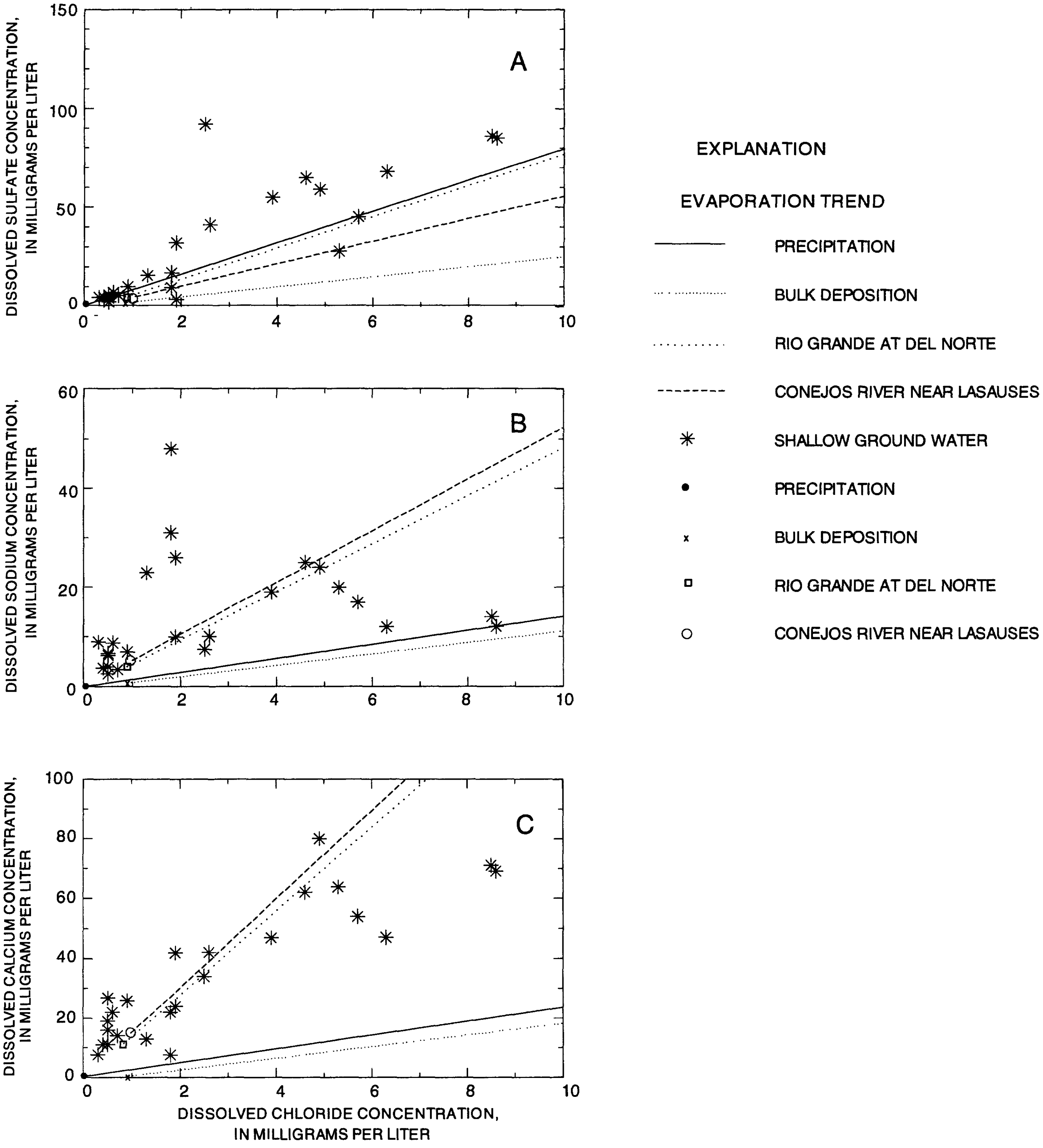


Figure 13.--Relation between (A) dissolved chloride and sulfate concentrations, (B) dissolved chloride and sodium concentrations, and (C) dissolved chloride and calcium concentrations in shallow ground water containing dissolved chloride concentrations less than 10 milligrams per liter in the San Luis Valley land-use study area.

The chloride and sodium plot shows that many of the ground-water samples have chloride and sodium concentrations similar to those of the surface water (fig. 13B). Several samples have less chloride or more sodium than surface water. Other ground-water samples plot along the surface-water evaporation trend; however, there is considerable variation in ground-water compositions. The variation in ground-water compositions suggests processes or chemical reactions occuring during infiltration or in the aquifer that affect sodium concentrations. Ground-water samples that plot above surface-water evaporation trends indicate processes that add sodium to the water but do not affect chloride concentrations.

The plot of chloride and calcium shows that many of the ground-water samples have chloride and calcium concentrations similar to those in surface water. Some of these samples contain more calcium than surface water and more calcium than precipitation or bulk deposition (fig. 13C). The larger calcium concentration in ground water relative to surface water could be due to recharge water dissolving calcite during infiltration. The saturation index for calcite in many of the ground-water samples with dissolved-solids concentrations less than 500 mg/L generally is less than 0.0, indicating that calcite would dissolve if present in the unsaturated zone or aquifer (table 7). Dissolution of calcite during infiltration would result in more calcium relative to chloride when compared to evaporation trends of the selected sources of recharge water.

On the basis of the chloride/sulfate, chloride/sodium, and chloride/calcium plots, many of the ground-water samples with chloride concentrations less than 10 mg/L are similar in composition to surface water or to surface water that has been concentrated by evaporation. This suggests that surface water could be recharging the ground water near some of the wells sampled. Comparison of shallow ground-water samples and other possible sources of recharge (ground water from the confined and unconfined aquifer) would be necessary to confirm surface water as the main source of recharge near these wells.

A plot of dissolved chloride and silica concentrations shows that ground water generally contains more silica than is found in surface water (fig. 14). Dissolved silica concentrations were generally less than 0.1 mg/L in precipitation and less than 0.5 in bulk deposition (snowmelt) in an area about 70 miles southeast of Alamosa (Anderholm and others, 1994). The larger silica concentrations in shallow ground water than in precipitation, bulk deposition, and surface water indicate that some process is occurring that results in increases in silica concentrations during recharge of precipitation or surface water. The San Juan Mountains are composed of volcanic rocks and are the source area for many of the basin-fill deposits in the San Luis Valley. Weathering of these volcanic rocks in the soil zone or shallow aquifer in the San Luis Valley could be the process that results in the relatively large silica concentrations in shallow ground water relative to precipitation and surface water.

Silica concentrations in shallow ground water do not increase, however, with increasing chloride concentration as was the case with sulfate, sodium, and calcium. This indicates that recharge water initially dissolves silica; as ground water or recharge water evaporates, however, some process such as precipitation of some mineral containing silica (such as amorphous quartz or chalcedony) must be limiting the silica concentration in the shallow ground water. The saturation index for amorphous quartz is generally less than 0.0 (table 7), thus amorphous quartz would tend to dissolve in water. Because the saturation index for chalcedony is greater than 0.0, chalcedony would tend to precipitate from shallow ground water (table 7).

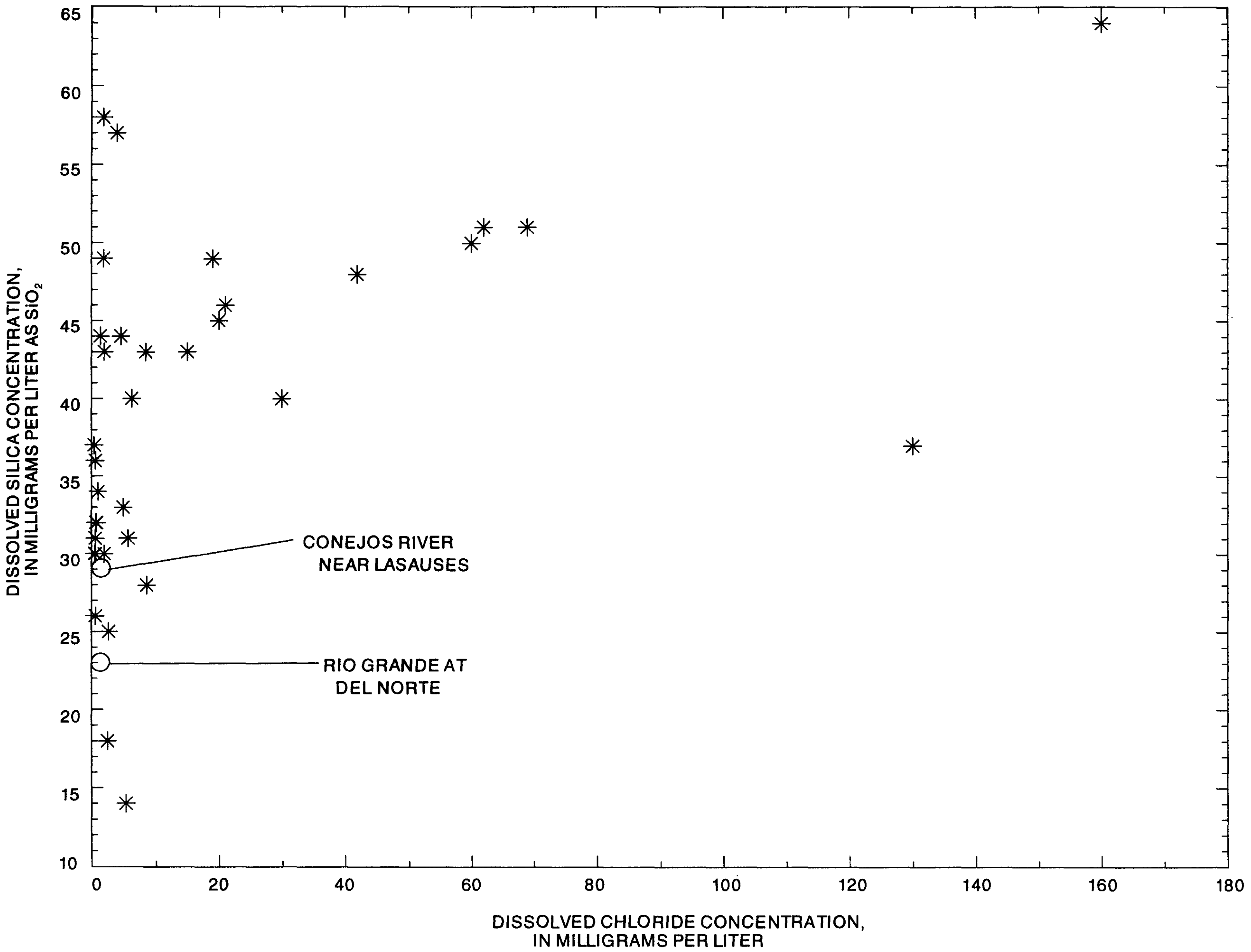


Figure 14.--Relation between dissolved chloride and silica concentrations in shallow ground water in the San Luis Valley land-use study area.

Fluoride concentrations in shallow ground water generally are less than 1.0 mg/L (app. 2). Likely sources of fluoride in shallow ground water are volcanic rocks and apatite (Hem, 1985, p. 121). Emery and others (1973, p. 21) said that fluoride concentrations are greater than about 1.3 mg/L in ground water from the confined aquifer over a large area in the San Luis Valley; they make no mention, however, of elevated fluoride concentrations in ground water from the unconfined aquifer. The fluoride concentrations in shallow ground water do not seem to be controlled by mineral precipitation.

Nutrients, Dissolved Organic Carbon, and Dissolved Oxygen

The occurrence and movement of nutrients in water in the unsaturated zone and in the aquifer are affected by microorganisms (Chapelle, 1993). Microbial processes can result in changes in the speciation of elements, which in turn affect how these elements will move in water. Ground-water samples were analyzed for nutrients including several nitrogen and phosphorous compounds, DOC, and dissolved oxygen (table 3). Microorganisms do not generally use one particular element without affecting other elements; therefore, cycling (the path of an element as it moves through the biosphere) of all nutrients can be related.

Nutrients in ground water can come from natural sources, such as dissolution of organic matter in the aquifer or precipitation, or from human activities, such as the application of fertilizers to agricultural crops. Under aerobic conditions (oxygen is present) ammonia can be oxidized to nitrate by microorganisms (nitrification). Nitrate is not adsorbed by silicate minerals and tends to move in water; therefore, the nitrogen species that is found in ground water as the result of leaching of fertilizers is nitrate. Under anaerobic conditions (oxygen is absent) nitrate can be reduced to nitrogen gas by microorganisms (denitrification). Phosphorous compounds are generally adsorbed by silicate minerals and therefore are not generally found in large concentrations in ground water. DOC in ground water can result from the partial oxidation of organic matter in the soil zone or in the aquifer. Complete oxidation of organic matter results in carbon dioxide (CO_2) gas. Some of this CO_2 will return to the atmosphere and some will dissolve in the water. Nitrate and ammonia are nitrogen compounds commonly found in precipitation at concentrations less than 1.0 mg/L (National Atmospheric Deposition Program, 1987). Phosphorus is found in precipitation at concentrations considerably below 1 mg/L. Fertilizers generally contain nitrogen and phosphorous compounds. The most common nitrogen compounds in fertilizers are ammonia or ammonium, which tend to adsorb to silicate minerals and, therefore, are not generally found in large concentrations in ground water (Chapelle, 1993, p. 249).

Oxygen in the atmosphere and unsaturated zone is dissolved by infiltrating water as it moves downward to the aquifer. Dissolved oxygen is consumed in the unsaturated zone and aquifer by the oxidation of organic matter, DOC, ammonia, and ammonium. The concentration of dissolved oxygen in ground water is therefore a function of the rate of oxygen transport to the aquifer and the rate of oxygen consumption in the aquifer. Dissolved oxygen is one of the most important constituents in determining which nutrients can occur/exist in an aquifer or ground water and the fate of these nutrients.

The median dissolved-oxygen concentration of 3 mg/L in water from the sampled wells suggests the presence of oxygen and aerobic conditions in most of the shallow aquifer in the San Luis Valley. A plot of dissolved oxygen and DOC shows that the larger dissolved-oxygen concentrations generally were in water having smaller DOC concentrations (fig. 15A). This is expected if dissolved oxygen is depleted in the water during the oxidation of organic matter and the flux of dissolved oxygen to the aquifer is less than the rate of oxidation of organic matter. If dissolved oxygen is not present in the aquifer, dissolution of organic matter in the unsaturated zone or aquifer could increase DOC concentrations because there would be little or no oxidation of the organic matter to CO_2 gas. Some of the larger DOC concentrations measured were in water containing little or no dissolved oxygen. Several samples, however, contained relatively large concentrations of both DOC and dissolved oxygen (fig. 15A). In these samples, the flux of dissolved oxygen to the aquifer must be greater than the consumption of oxygen by the oxidation of organic matter.

The solubility of nitrogen is affected by the oxidation state of the ground water or aquifer as discussed above. Nitrogen in ground water with dissolved oxygen would tend to be as nitrate. In contrast, water with little or no dissolved oxygen might not have nitrate due to conversion of nitrate to nitrite, ammonia, or ammonium. Ammonia is converted to nitrate in a process referred to as nitrification. A plot of dissolved oxygen and dissolved nitrite plus nitrate shows that water with nitrate concentrations greater than 10 mg/L generally had dissolved-oxygen concentrations greater than about 1 mg/L (fig. 15B). In the areas where the larger nitrate concentrations were detected, nitrogen fertilizers are being oxidized and nitrate is being leached from the unsaturated zone by infiltrating water. Figure 15B also shows that dissolved oxygen is measured at relatively large concentrations and no dissolved nitrate was found in some of the ground water, indicating that nitrate probably is not being leached from land surface down into the aquifer in the area of these wells. Water from several wells contained little dissolved oxygen (less than 0.5 mg/L); however, nitrate concentrations in water from these wells ranged from 2 to 13 mg/L (fig. 15B). DOC concentrations in water from these wells are greater than 3 mg/L (fig. 15C), possibly suggesting that dissolved oxygen is consumed by the oxidation of organic matter and that nitrate has not been reduced because microorganisms that cause denitrification to occur are not present or the flux of infiltrating waters containing nitrate is greater than the reduction of nitrate. The plot of DOC and nitrate concentrations shows that nine samples contained DOC concentrations ranging from about 1 to 4 mg/L and nitrate concentrations greater than 10 mg/L (fig. 15C). The samples with nitrate concentrations greater than 10 mg/L also generally contained dissolved-oxygen concentrations greater than 2 mg/L. Why the nitrate and dissolved-oxygen concentrations are so large when DOC is present in the water is unknown. The recharge rates or fluxes of nitrate, DOC, and oxygen could be larger than the rate at which the microorganisms can consume the supply of these nutrients. Pesticide residues that are toxic to microorganisms could also affect microorganism populations in the unsaturated zone, which could affect the consumption of nutrients in the unsaturated zone.

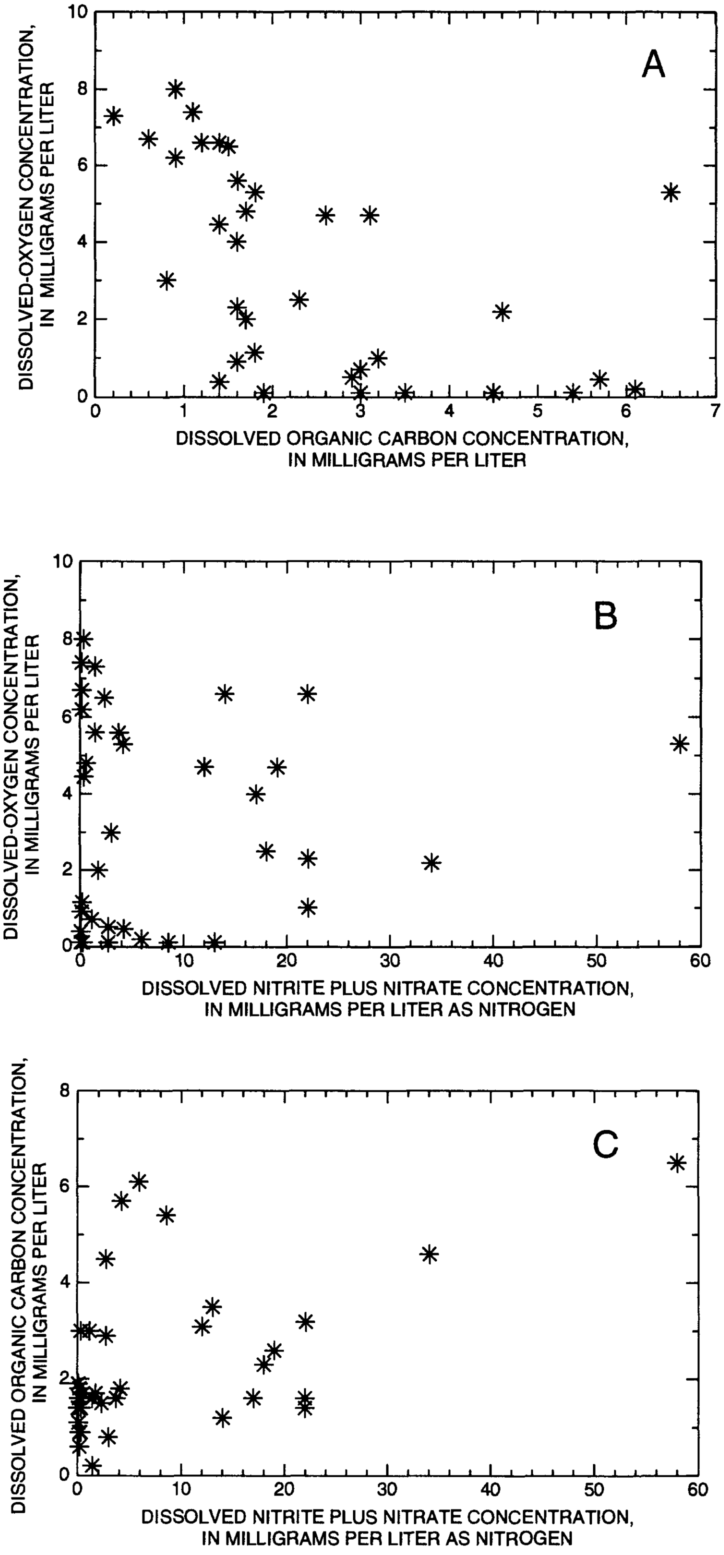


Figure 15.--Relation between (A) dissolved organic carbon and dissolved-oxygen concentrations, (B) dissolved nitrite plus nitrate and dissolved-oxygen concentrations, and (C) dissolved nitrite plus nitrate and dissolved organic carbon concentrations in shallow ground water in the San Luis Valley land-use study area.

The elevated nitrate concentrations in shallow ground water are indicative of leaching of fertilizers from the land surface. As early as 1969, Emery and others (1973, p. 19) found nitrate concentrations greater than 10 mg/L in the unconfined aquifer near Center. Emery and others (1973) said that nitrate concentrations decrease with increasing well depth. Edelmann and Buckles (1984) also detected nitrate concentrations greater than 10 mg/L near Center and decreasing nitrate concentrations with increasing well depth. Eddy-Miller (1993) measured nitrate concentrations ranging from 12 to 75 mg/L in water from seven wells screened near the water table in an irrigated field in the San Luis Valley. Eddy-Miller (1993, p. 53) reported that nitrate concentrations in water from these wells was largest in late June and calculated that nitrogen was leaching from the soil in the area. LeStrange (1995, p. 51-64) showed that nitrogen leaching does occur in the San Luis Valley and calculated nitrogen leaching rates of -5.3 to 224 pounds of nitrogen as N per acre. LeStrange (1995, p. 44) measured total nitrate stored in the unsaturated zone ranging from 21 to 267 pounds as N per acre. Based on the data collected during this study and data collected by other investigators, nitrogen fertilizers have been and continue to leach into shallow ground water, and ground water in parts of the San Luis Valley has been affected by this leaching.

Trace Elements

Trace elements in ground water can come from a variety of sources. Trace elements in ground water can result from the dissolution of minerals that naturally are found in the aquifer: trace-element concentrations greater than 1 mg/L are commonly found in areas of large concentrations of metallic ores. In ground water, trace elements can also result from human activities such as mining, application of pesticides, burning of fossil fuels, smelting of ores, and improper disposal of industrial wastes. Weathering of waste rock near mining activities is a common source of trace elements in ground water. Arsenic and copper have been used in pesticides and therefore can be leached by water infiltrating to the aquifer. Burning of fossil fuels and smelting of metallic ores are sources of trace elements to the atmosphere. These trace elements can be deposited over large areas as dust or in precipitation and leach into ground water. Industrial uses of trace elements can result in waste that, if improperly disposed of, can cause ground-water contamination. Because a detailed discussion of the trace-element chemistry in the study area is beyond the scope of this report, some of the more general findings are presented for trace elements found at concentrations greater than their MRL's.

Concentrations of trace elements in water can be controlled by the solubility of the minerals containing the elements, the oxidation/reduction state of the ground water, complexing by organic ligands, and adsorption/coprecipitation (Drever, 1988). The pH of ground water can also affect the concentration of trace elements in ground water, but did not seem to be an important factor in the San Luis Valley because of the small range in pH in ground water. Solubility equilibria generally provide for the upper limits of trace-element concentrations in solution, but adsorption and the other factors listed above also can control concentrations found in ground water. Many trace elements can occur/exist in various oxidation states, and the solubility of various minerals is dependent on the oxidation state of the element or the environment the mineral is in such as the aquifer or ground water. For example, manganese is more soluble in the reduced form than in the oxidized form, thus manganese concentrations are generally small (less than 50 μg/L) in water containing dissolved-oxygen concentrations greater than 1 mg/L.

Various trace elements form complexes with organic solids in the aquifer, thereby removing the trace elements from solution. Trace elements can also form complexes with DOC. In these cases, increases in trace-element concentrations are associated with large DOC concentrations. Iron and manganese oxides in aquifers have large adsorption capacities and affinities for some trace elements (Drever, 1988). Adsorption of many trace elements can result in decreases in the concentrations of dissolved trace elements, especially in the presence of iron and manganese oxides. Iron and manganese oxides would be present in the aquifer where ground water contains dissolved oxygen. Dissolution of iron and manganese oxides containing adsorbed trace elements could result in increases in dissolved trace elements.

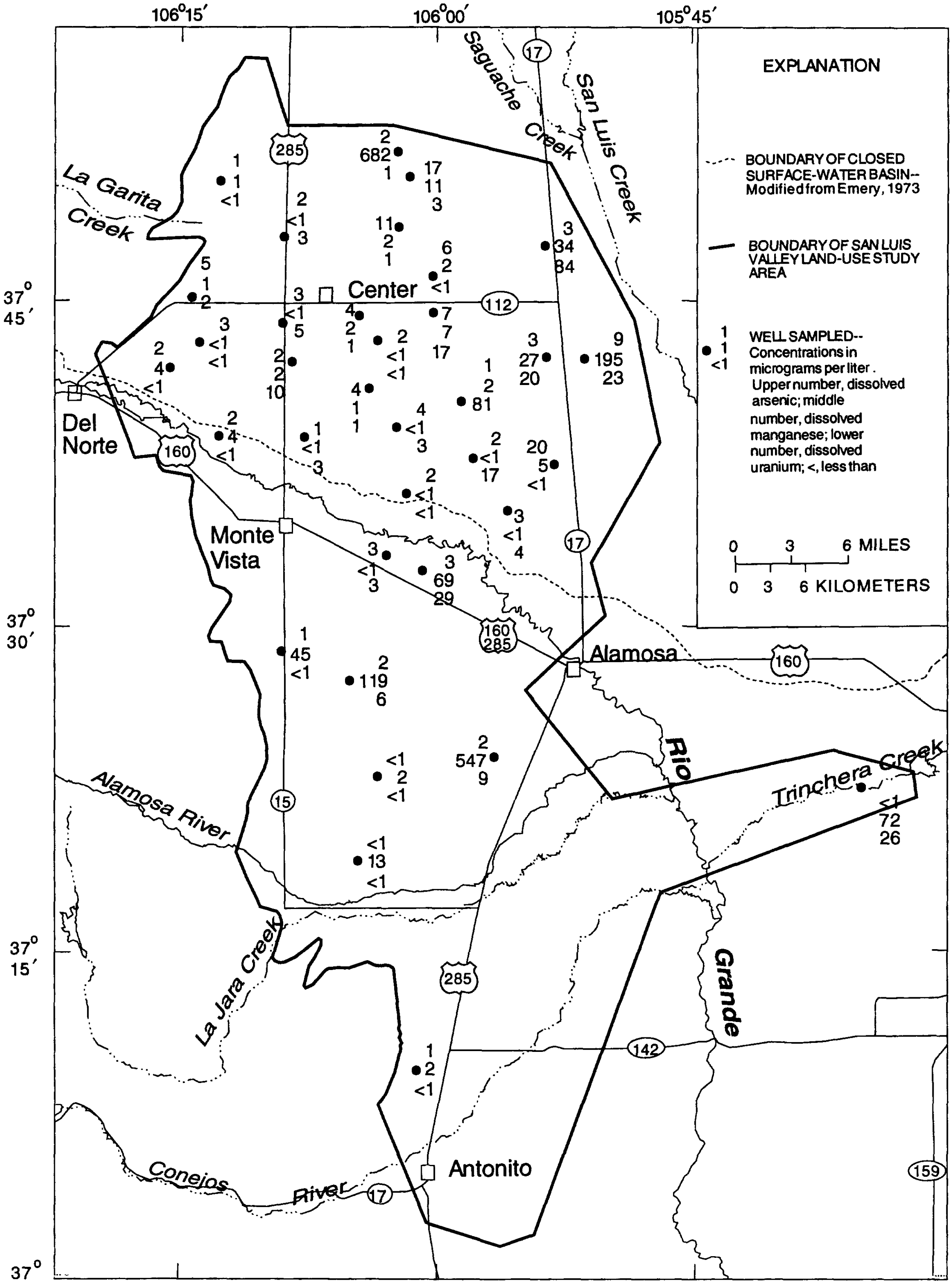
Areal plots of several trace elements show that larger concentrations were found in specific parts of the San Luis Valley. Areal plots of most trace-element concentrations did not show patterns in the study area that would indicate specific processes affecting trace-element concentrations in parts of the San Luis Valley. The largest arsenic concentrations were found in water from wells in the northern and eastern parts of the study area in the closed basin (fig. 16). Large manganese concentrations generally were found in water from wells along the eastern margin of the study area in the closed basin and in the part of the study area drained by the Rio Grande (fig. 16). Uranium concentrations generally were larger in water from wells along the eastern side of the study area (fig. 16).

Aluminum, which is one of the most abundant elements on the Earth, was found at a concentration greater than 1.0 μg/L in all samples analyzed (app. 2). Many aluminum concentrations were less than 20 μg/L; however, the samples containing aluminum concentrations greater than 20 μg/L had specific-conductance values less than about 400 μS/cm (fig. 17). Why the largest aluminum concentrations were found in some of the most dilute waters sampled is unknown.

Dissolved arsenic concentrations ranged from less than 1.0 to 20 μg/L, and the median concentration was 3 μg/L (table 6). Arsenic adsorbs to iron oxides in aerobic conditions (Welch and others, 1988). Arsenic concentrations are not smaller in ground water containing larger dissolved-oxygen concentrations, indicating that adsorption on iron and manganese oxides does not seem to affect arsenic concentrations (fig. 18A). Also, arsenic concentrations do not increase with increasing DOC concentrations, suggesting that arsenic is not limited by dissolved organic complexes (fig. 18B). The variation in dissolved arsenic concentrations may be due to the variation in the minerals in the aquifer that contain arsenic because many of the water samples with larger arsenic concentrations were from wells in a small area (fig. 16).

The median dissolved barium concentration was 52 μg/L, the largest median concentration of any trace element (table 6). The solubility of barium may be controlled by the saturation equilibria of barite ($BaSO_4$). About one-third of the samples were near saturation or supersaturated with respect to barite (table 7). In many samples, the saturation index of barite is considerably less than 0.0, indicating that barite, if present in the aquifer, tends to dissolve in ground water.

Dissolved copper concentrations ranged from less than 1 μg/L to 10 μg/L (table 6) and increased with increasing DOC concentrations (fig. 19), possibly suggesting that copper is forming organic complexes with DOC. Copper is most soluble in the reduced oxidation state. Because several samples with larger copper concentrations contained dissolved oxygen, however, organic complexes are probably the main factor controlling dissolved copper concentration.



Base from U.S. Geological Survey digital data, 1:100,000 scale, various dates

Universal Transverse Mercator projection, zone 13

Figure 16.--Concentrations of dissolved arsenic, manganese, and uranium in shallow ground water in the San Luis Valley land-use study area.

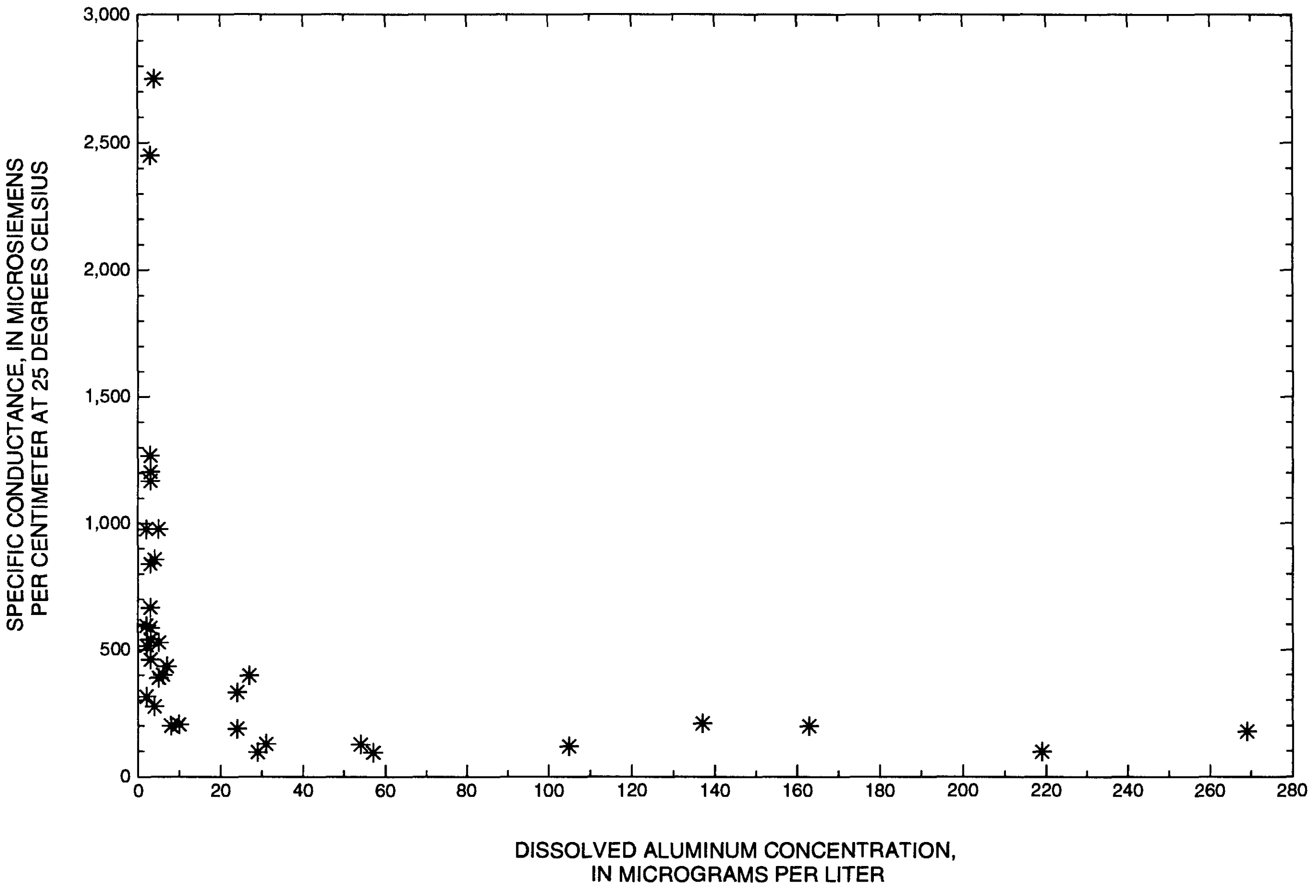


Figure 17.--Relation between dissolved aluminum concentration and specific conductance in shallow ground water in the San Luis Valley land-use study area.

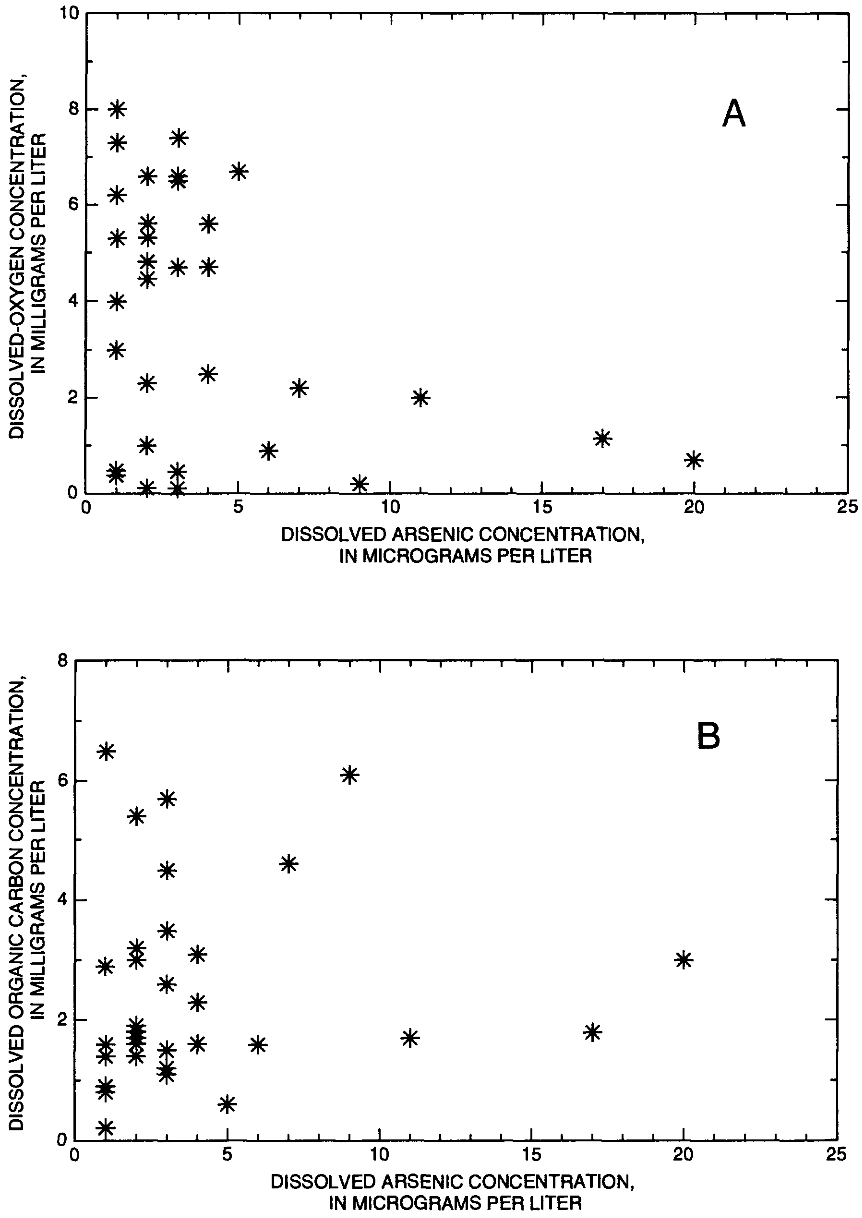


Figure 18.--Relation between (A) dissolved arsenic and dissolved-oxygen concentrations and (B) dissolved arsenic and dissolved organic carbon concentrations in shallow ground water in the San Luis Valley land-use study area.

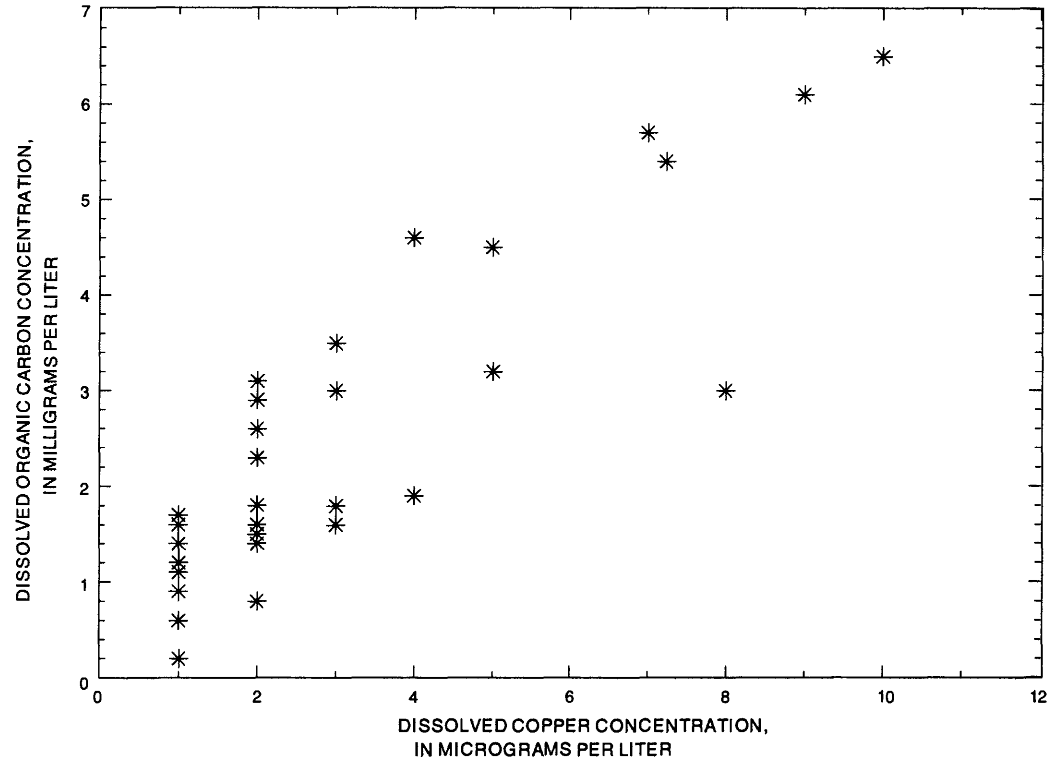


Figure 19.--Relation between dissolved copper and dissolved organic carbon concentrations in shallow ground water in the San Luis Valley land-use study area.

Iron and manganese are trace elements that behave similarly in ground water because their solubilities are dependent on the oxidation/reduction state of the water/aquifer (Hem, 1985). Iron and manganese are soluble in anaerobic environments and relatively insoluble in aerobic environments. Dissolved iron and manganese concentrations in shallow ground water in the study area are small, which is expected considering that dissolved-oxygen concentrations in about 75 percent of the wells sampled were greater than 0.5 mg/L, indicating aerobic conditions. The dissolved iron concentrations measured were less than 10 μg/L in more than one-half of the samples and had a maximum concentration of 67 μg/L (table 6). Dissolved manganese concentrations ranged from less than 1.0 μg/L to 682 μg/L, and the median was 2 μg/L (table 6). The largest manganese concentrations were found in water with dissolved-oxygen concentrations of 0.1 mg/L or less (fig. 20).

Dissolved molybdenum concentrations ranged from less than 1.0 μg/L to 52 μg/L, and the median concentration was 2 μg/L (table 6). Molybdenum can occur in several different oxidation states, and the solubility equilibria are affected by the oxidation/reduction potential of the water/aquifer. The largest molybdenum concentrations were in water having dissolved-oxygen concentrations generally less than 2.5 mg/L; however, relatively large molybdenum concentrations were not found in all waters having dissolved-oxygen concentrations less than 2.5 mg/L.

Dissolved uranium concentrations ranged from less than 1.0 µg/L to 84 µg/L, and the median concentration was 3 µg/L (table 6). In general, uranium is soluble in aerobic environments and relatively insoluble in anaerobic environments. Uranium concentrations in ground water are affected by adsorption by iron oxides and complexes with carbonate (Hem, 1985). Some of the largest uranium concentrations were measured in water having dissolved-oxygen concentrations less than about 0.5 mg/L, indicating that the more oxidizing ground water did not necessarily have the largest uranium concentrations. Uranium concentrations increase with increasing bicarbonate concentrations, indicating that uranium forms uranyl complexes with carbonate species in the study area and these complexes affect dissolved uranium concentrations (fig. 21).

On the basis of areal distribution and range of trace-element concentrations, human activities have not caused widespread trace-element contamination in shallow ground water. Human activities could result in changes in the oxidation/reduction state of the ground water/aquifer or increases in the DOC concentrations in ground water, and therefore could affect the concentration of various trace elements in ground water. Whether human activities in the San Luis Valley have resulted in changes in the oxidation/reduction state in the aquifer or have otherwise affected the concentration of trace elements in the aquifer is not known because no historical data for the shallow part of the aquifer are available to compare with data collected for this study.

Radionuclides

Radionuclides in ground water are from natural sources, such as the weathering of rocks and interaction of cosmic rays with atmospheric particles, or from human activities, such as testing of nuclear weapons and industrial/medical uses of radionuclides. Dissolved gross alpha is a measure of the alpha radiation, positively charged helium nuclei, emitted from a filtered sample. Suspended gross alpha is a measure of the alpha radiation in the part of the sample that does not pass through a 0.45-micron-pore-sized filter. The main alpha-emitting substances in ground water are decay products of uranium and thorium, which generally occur naturally. Dissolved gross beta is a measure of beta radiation, electrons or positrons, emitted from a filtered sample. Suspended gross alpha is a measure of the beta radiation in the sample that does not pass through a 0.45-micron-pore-sized filter. The main beta-emitting substances in ground water are potassium-40, which occurs naturally, and cesium-137 and strontium-90, which are related to human activities. The measurement of gross alpha activity or gross beta activity of a particular sample is a measure of all of the alpha- or beta-emitting radionuclides. Gross alpha activities are reported in terms of the amount of natural uranium of equilibrium thorium-230 that would give the same count rates. Gross beta activities are reported in terms of the equilibrium strontium-90/yttrium-90 or cesium-137 that would give the same count rates. Gross alpha and gross beta activities in the tables are reported as equivalent concentrations of these different radionuclides.

Radon-222 concentrations in ground water are the result of the decay of radium-226 in the aquifer material, which is a function of the amount of uranium in aquifer materials and, where reducing conditions exist, dissolved radium-226 in the ground water (Thomas and others, 1993). Radon-222 is a gas at the temperature and pressure found in ground water near the land surface; therefore, degassing of radon from shallow ground water can occur.

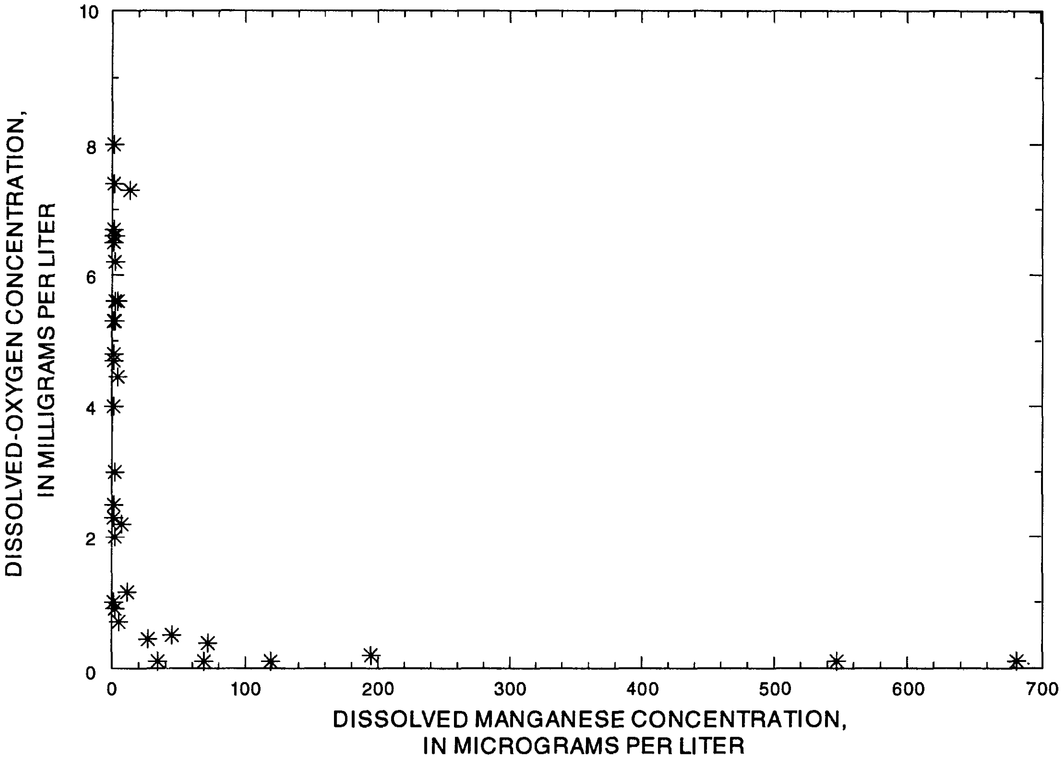


Figure 20.--Relation between dissolved manganese and dissolved-oxygen concentrations in shallow ground water in the San Luis Valley land-use study area.

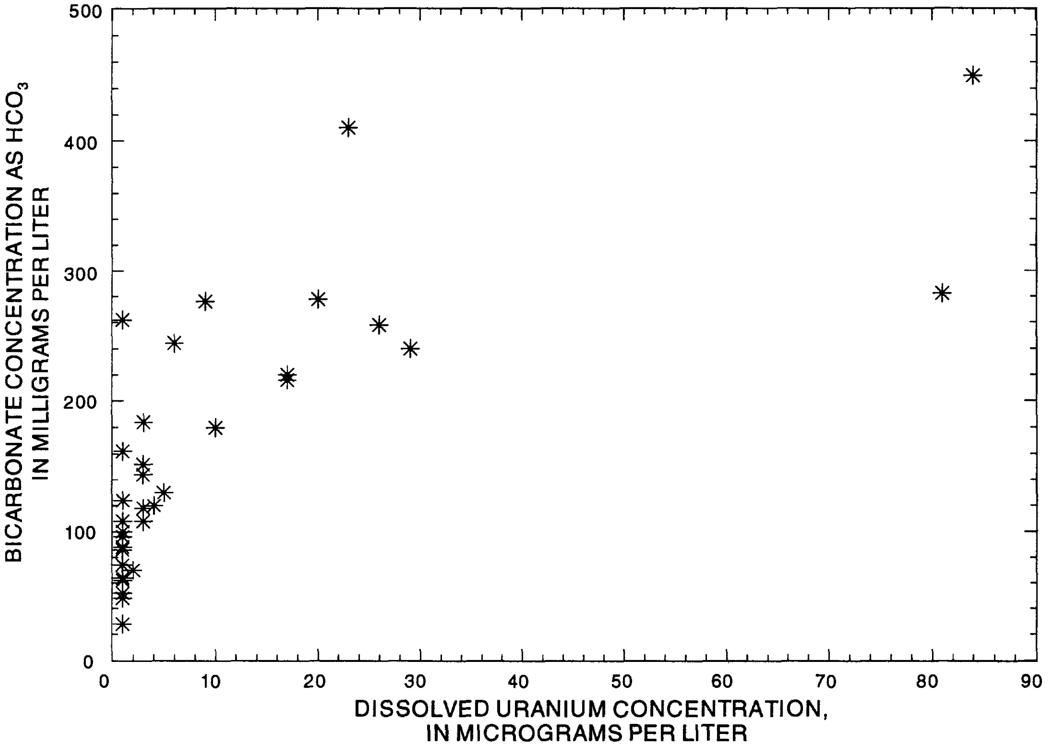


Figure 21.--Relation between dissolved uranium and bicarbonate concentrations in shallow ground water in the San Luis Valley land-use study area.

Uranium generally is the most abundant alpha-emitting radionuclide. Uranium concentrations were analyzed directly and ranged from less than 1.0 to 84 μg/L, and the median concentration was 3 μg/L (table 6). Gross alpha activity was measured and reported as equivalent uranium concentration (this method assumes that all alpha activity is due to radioactive decay of uranium). Dissolved gross alpha concentrations ranged from less than 0.6 to 130 μg/L, and the median concentration was 3.5 μg/L (table 6). A plot of dissolved gross alpha activity as uranium and dissolved-uranium concentration shows that a large amount of gross alpha activity measured in the samples is accounted for by the uranium concentration in the samples (fig. 22A). Many samples have dissolved gross alpha activities as uranium slightly greater than what would be predicted from the uranium concentration (data plot below 1:1 line), indicating that a small amount of dissolved gross alpha activity is from alpha-emitting radionuclides other than uranium. The difference could also be accounted for by counting uncertainties (app. 2).

Suspended gross-alpha concentrations were less than 0.6 μg/L as U in 30 of the 35 samples (table 6). All but two samples had suspended gross alpha concentrations less than 1.0 μg/L as U, suggesting that suspended gross alpha concentrations in shallow ground water in the San Luis Valley generally are small.

Potassium-40, a natural isotope of potassium, is a major source of gross beta activity in ground water. Potassium concentrations in ground-water samples ranged from less than 0.1 to 19 mg/L, and the median concentration was 5.2 mg/L (table 6). Dissolved gross beta activity reported as Sr-90/Y-90 ranged from 1.3 to 35 pCi/L, and the median concentration was 5 pCi/L (table 6). Gross beta activity from potassium-40 (in picocuries per liter) can be estimated by multiplying potassium concentrations (in milligrams per liter) by 0.818, which assumes a natural ratio of potassium-40 to potassium of 0.0117 percent and a half-life of potassium-40 of 1.28 X 10^9 years (Thomas and others, 1993, p. 463). A plot of dissolved gross beta activity as Sr-90/Y-90 and dissolved potassium shows that a large part of gross beta activity is the result of potassium-40 (fig. 22B).

Welch and others (1995) indicated that uranium-238 progeny grow in the samples between the time of collection and time of analysis and can result in significant beta activity that is distinct from the beta activity of water in the aquifer. The effect of the uranium-238 progeny can be estimated by subtracting out the beta activity due to potassium-40 from the dissolved gross beta activity and plotting the adjusted value against the uranium concentration in the sample (fig. 22C). This plot indicates that in most samples all beta activity is attributed to potassium-40 (adjusted values about 0). In cases where the adjusted value is greater than 0.0, however, the adjusted beta activity generally increases with increasing uranium concentration. The increase in the adjusted beta activity with increasing uranium concentration may indicate that the uranium-238 progeny are the source of the beta activity not from potassium-40. One sample has a beta activity much larger than can be explained by the uranium and potassium concentrations (fig. 22C). The reason for the excess gross beta activity in this sample is unknown but could be due to counting uncertainty.

Suspended gross beta activities were greater than 0.6 pCi/L as Sr-90/Y-90 in 25 of the 35 samples (table 6). Most suspended gross beta activities were less than dissolved gross beta activities, indicating that most gross beta activity in the samples was dissolved.

The amount of radon-222 in ground water is a function of the amount of uranium and radium-226 in the aquifer materials and radium-226 dissolved in the ground water. Radon-222 concentrations measured ranged from 700 to 1,900 pCi/L, and the median was 1,300 pCi/L (table 6). The largest radon-222 concentrations are not associated with samples that have large dissolved uranium concentrations (fig. 22D). The relatively large radon-222 concentrations measured in the study area suggest the presence of uranium in the aquifer.

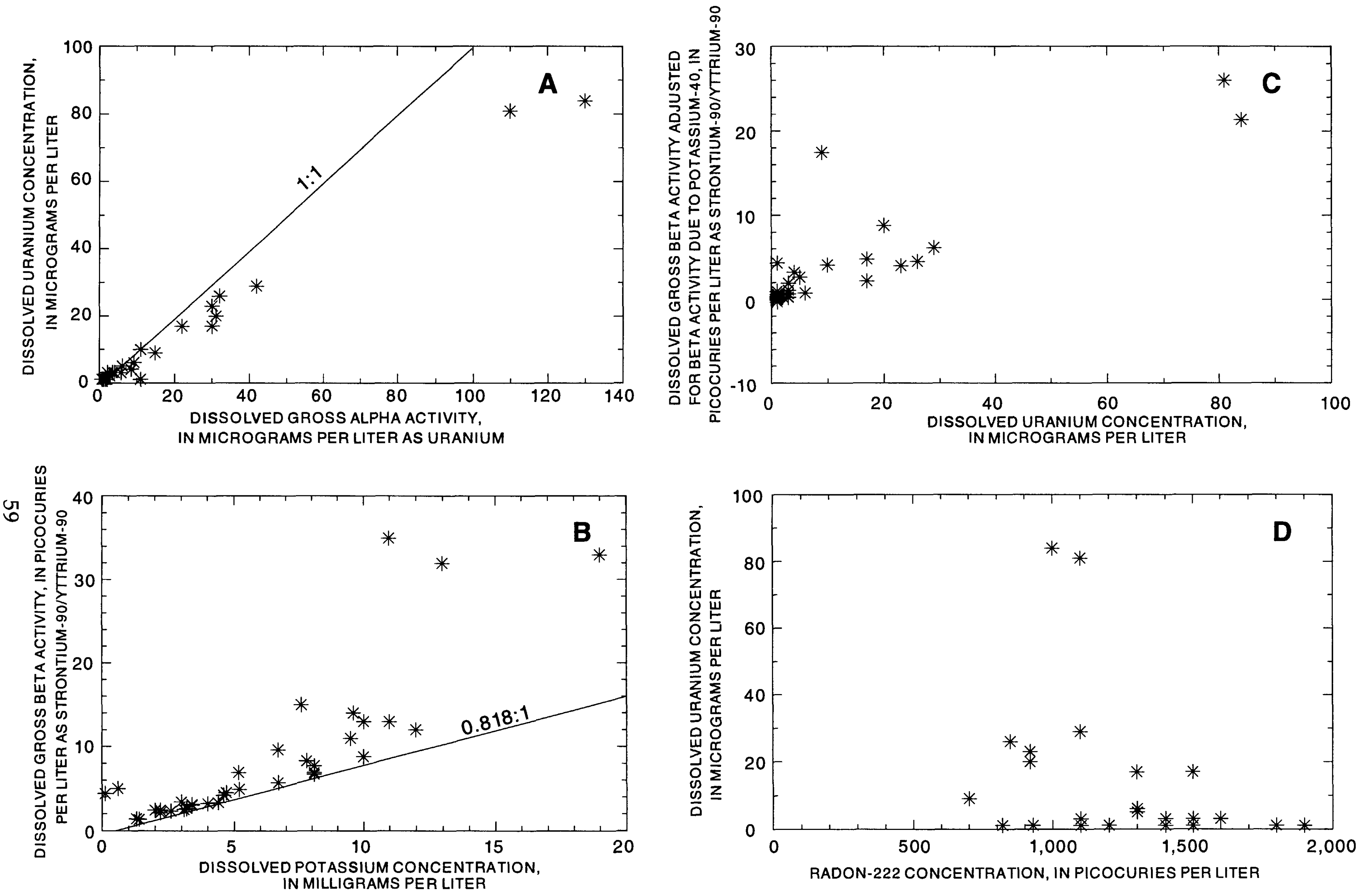


Figure 22.--Relation between (A) dissolved gross alpha activity and dissolved uranium concentration, (B) dissolved potassium concentration and dissolved gross beta activity, (C) dissolved uranium concentration and dissolved gross beta activity adjusted for beta activity due to potassium-40,and (D) radon-222 and dissolved uranium concentrations in shallow ground water in the San Luis Valley land-use study area.

It is not possible to determine whether human activities have affected the concentration or activity of radionuclides in ground water in the study area. Gross alpha and gross beta activities measured in the ground water are from naturally occurring elements (uranium and potassium). The concentrations of these naturally occurring elements could be affected by human activities; documenting or speculating how the concentrations of these elements have been affected is not possible.

Volatile Organic Compounds and Pesticides

Relatively few synthetic organic compounds were detected in ground water in the study area, indicating no widespread contamination of the aquifer by synthetic organic compounds as the result of human activities. A VOC detected in water from one well and pesticides detected in water from five shallow wells suggest that synthetic organic compounds in the soil have moved downward into the aquifer in some areas although it does not appear to be widespread. It is not possible to determine whether deeper parts of the aquifer have been affected by synthetic organic compounds using the data collected during this investigation. However, shallow ground water would likely be the first part of the aquifer to be affected by leaching of organic compounds downward through the unsaturated zone.

SUMMARY

The shallow ground-water quality in an agricultural area of the San Luis Valley was evaluated and studied to determine how natural and human factors affect the water quality. Thirty-five shallow wells were installed, and water samples were collected from these wells and analyzed for selected dissolved common constituents, nutrients, trace elements, radionuclides, and synthetic organic compounds.

The San Luis Valley is a high intermontane valley where irrigated agriculture is a dominant land use. Center-pivot overhead sprinklers are used to irrigate alfalfa, native hay, barley, wheat, potatoes, and other vegetables in much of the valley. The area of study was limited to the part of the valley where depth to water is generally less than 25 feet and the area is irrigated with center-pivot overhead sprinklers.

The dissolved-solids concentration of shallow ground water in the study area ranges from 75 to 1,960 mg/L. The largest median concentration of cations was for calcium, and the largest median concentration of anions was for bicarbonate in shallow ground water. Much of the shallow ground water containing smaller dissolved-solids concentrations is similar in composition to that in surface water, which could be the source of recharge for the ground water. Silica concentrations in shallow ground water generally are greater than those measured in surface water, indicating processes whereby silica is dissolving in the water.

Water from 11 of the 35 wells sampled had nitrite plus nitrate concentrations greater than 10 mg/L as N, which is the EPA MCL. The elevated nitrite plus nitrate concentrations indicate nitrogen fertilizers leaching into the shallow ground water.

Trace-element concentrations were relatively small in most samples. Aluminum, barium, and manganese were the only trace elements detected at concentrations greater than 100 μg/L in one or more samples. Five samples contained uranium concentrations greater than the EPA proposed MCL of 20 μg/L. It is not possible to determine whether human activities have resulted in changes in the oxidation/reduction state of the aquifer or in other factors that would affect the concentrations of trace elements in shallow ground water.

Water from eight wells exceeded the MCL for gross alpha activity. Most gross alpha activity is from uranium dissolved in ground water. Most gross beta activity is from potassium-40 dissolved in ground water. All of the water sampled exceeded the proposed MCL for radon-222.

The VOC methyltertbutylether, a gasoline additive, was detected in water from one well at a concentration of 0.6 μg/L. One or more pesticides were detected in water from five wells. Metribuzin was detected in water from three wells at concentrations ranging from an estimated 0.005 to 0.017 μg/L. Metolachlor, at a concentration of 0.072 μg/L, was detected in one sample; prometon, at a concentration of 0.01 μg/L, was detected in one sample; and p,p'-DDE, at an estimated concentration of 0.002 μg/L, was detected in one sample. The EPA lifetime health advisory concentrations for metolachlor, metribuzin, and prometon are 100 μg/L, which is much larger than the concentrations measured in shallow ground water. On the basis of the few synthetic organic compounds detected and their relatively small concentrations, no widespread contamination of shallow ground water in the study area has occurred as the result of human activities.

REFERENCES

Anderholm, S.K., Roybal, R.G., Risser, Dennis, and Somers, Georgene, 1994, Analysis of meteorological data and water chemistry of Latir Lakes, Taos County, New Mexico, 1985-88: U.S. Geological Survey Water-Resources Investigations Report 93-4113, 129 p.

Bohmont, B.L., 1991, Colorado pesticide use survey, estimated use--1989: Fort Collins, Colorado State University Cooperative Extension, 43 p.

Bureau of Reclamation, 1987, The San Luis Valley Project - Closed Basin Division design and planning of the project: Bureau of Reclamation Public Information Packet - Design and Planning, June 1987, 15 p.

Burroughs, R.L., 1981, A summary of the geology of the San Luis Basin, Colorado-New Mexico, *with emphasis on the* Geothermal potential for the Monte Vista Graben: Colorado Geological Survey Special Publication 17, 30 p.

Chapelle, F.H., 1993, Ground-water microbiology & geochemistry: New York, N.Y., John Wiley & Sons, Inc., 424 p.

Drever, J.I., 1988, The geochemistry of natural waters: Englewood Cliffs, N.J., Prentice Hall, Inc., 437 p.

Durnford, D.S., Thompson, K.R., Ellerbroek, D.A., Loftis, J.C., Davies, G.S., and Knutson, K.W., 1990, Screening methods for groundwater pollution potential from pesticide use in Colorado agriculture: Colorado Water Resources Research Institute Completion Report Number 157, 81 p.

Eddy-Miller, C.A., 1993, Evaluation of shallow ground water wells as a method of monitoring nitrate leaching in the San Luis Valley: Fort Collins, Colorado State University, unpublished M.S. thesis, 77 p.

Edelmann, Patrick, and Buckles, D.R., 1984, Quality of ground water in agricultural areas of the San Luis Valley, south-central Colorado: U.S. Geological Survey Water-Resources Investigations Report 83-4281, 37 p.

REFERENCES--Continued

Ellerbroek, D.A., Durnford, D.S., and Pearson, C., 1992, Monitoring groundwater quality in the San Luis Valley: Conference proceedings from Colorado Water Engineering and Management Conference, March 2-3, 1992, p. 121-127.

Emery, P.A., Patten, E.P., Jr., and Moore, J.E., 1975, Analog model study of the hydrology of the San Luis Valley, south-central Colorado: Colorado Water Conservation Board Ground-Water Circular 29, 21 p.

Emery, P.A., Snipes, R.J., Dumeyer, J.M., and Klein, J.M., 1973, Water in the San Luis Valley, south-central Colorado: Colorado Water Conservation Board Water-Resources Circular 18, 26 p.

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Friedman, L.C., and Erdmann, D.E., 1982, Quality assurance practices for the chemical and biological analyses of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A6, 181 p.

Hearne, G.A., and Dewey, J.D., 1988, Hydrologic analysis of the Rio Grande Basin north of Embudo, New Mexico, Colorado and New Mexico: U.S. Geological Survey Water-Resources Investigations Report 86-4113, 244 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Huntley, David, 1976, Ground-water recharge to the aquifers of northern San Luis Valley, Colorado: Golden, Colorado School of Mines, Remote Sensing Report 76-3, 247 p.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program--Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95-399, 113 p.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program--Selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95-398, 69 p.

Leonard, G.J., and Watts, K.R., 1989, Hydrogeology and simulated effects of ground-water development on an unconfined aquifer in the Closed Basin Division, San Luis Valley, Colorado: U.S. Geological Survey Water-Resources Investigations Report 87-4284, 41 p.

LeStrange, S.L., 1995, Identification of spatial patterns in nitrate leaching: Fort Collins, Colorado State University, unpublished Ph.D. dissertation, 97 p.

Lewis, W.M., Jr., Grant, M.C., and Saunders, J.F., III, 1984, Chemical patterns of bulk atmospheric deposition in the State of Colorado: Water Resources Research, v. 20, no. 11, p. 1691-1704.

National Atmospheric Deposition Program, 1987, NADP/NTN Data Report--Precipitation chemistry, 1 July - 31 December, 1986, v. IX, no. 2: Fort Collins, Colorado State University, National Resource Ecology Laboratory, 216 p.

REFERENCES--Continued

National Atmospheric Deposition Program (NRSP-3)/National Trends Network, 1992: NADP/NTN coordination office, Fort Collins, Colo.

National Oceanic and Atmospheric Administration [n.d.], Climatological data annual summary, Colorado, 1994: U.S. Department of Commerce, v. 99, no. 13, 36 p.

Parkhurst, D.L., Thorstenson, D.C., and Plummer, L.N., 1980, PHREEQE--A computer program for geochemical calculations: U.S. Geological Survey Water-Resources Investigations 80-96, 195 p.

Powell, W.J., 1958, Ground-water resources of the San Luis Valley, Colorado: U.S. Geological Survey Water-Supply Paper 1379, 284 p.

Pritt, J.W., and Raese, J.W., 1992, Quality assurance/quality control manual, National Water Quality Laboratory: U.S. Geological Survey Open-File Report 92-495, 33 p.

Rio Grande Compact Commission, 1994, Report to the Governors of Colorado, New Mexico, and Texas: 51 p.

Robinson, T.W., Jr., and Waite, H.A., 1938, Ground water in the San Luis Valley, Colorado, *in* Part 6--The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937, volume I: Washington, D.C., National Resources Committee, p. 226-267.

Rose, D.L., and Schroeder, M.P., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of volatile organic compounds in water by purge and trap capillary gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 94-708, 26 p.

Sax, N.I., and Lewis, R.J., Sr., eds., 1987, Hawley's condensed chemical dictionary (11th ed.): New York, Van Nostrand Reinhold, 1288 p.

Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of ground-water-quality sampling network: U.S. Geological Survey Water-Resources Investigations Report 90-4101, 109 p.

Siebenthal, C.E., 1910, Geology and water resources of the San Luis Valley, Colorado: U.S. Geological Survey Water-Supply Paper 240, 128 p.

Squillace, P.J., Zogorski, J.S., Wilber, W.G., and Price, C.V., 1995, A preliminary assessment of the occurrence and possible sources of MTBE in ground water of the United States, 1993-94: U.S. Geological Survey Open-File Report 95-456, 30 p.

Thatcher, L.L., Janzer, V.L., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A5, 95 p.

Thomas, J.M., Welch, A.H., Lico, M.S., Hughes, J.L., and Whitney, Rita, 1993, Radionuclides in ground water of the Carson River Basin, western Nevada and eastern California, U.S.A.: Applied Geochemistry, v. 8, p. 447-471.

Thompson, K.L., 1993, Nitrate contamination in the unconfined aquifer of the San Luis Valley: Fort Collins, Colorado Sate University, unpublished Senior Honors Thesis, 125 p.

REFERENCES--Concluded

Timme, P.J., 1995, National Water Quality Laboratory 1995 services catalog: U.S. Geological Survey Open-File Report 95-352, 120 p.

Ugland, B.J., Cochran, B.J., Hiner, M.M., and Steger, R.D., 1994, Water resources data, Colorado, water year 1993, Volume 1. Missouri River Basin, Arkansas River Basin, and Rio Grande Basin: U.S. Geological Survey Water-Data Report CO-93-1, 518 p.

Ugland, B.J., Maura, W.S., Steger, R.D., and O'Neill, G.B., 1995, Water resources data, Colorado, water year 1994, Volume 1. Missouri River Basin, Arkansas River Basin, and Rio Grande Basin: U.S. Geological Survey Water-Data Report CO-94-1, 418 p.

U.S. Department of Commerce, 1991, 1990 census of population and housing; Summary population and housing characteristics, Colorado: 1990 CPH-1-73, variously paged.

U.S. Environmental Protection Agency, 1986, Advance notice of proposed rule making, National primary drinking water regulations, Radionuclides (section 141.50 of part 141): U.S. Federal Register, v. 51, no. 189, September 30, 1986, p. 34836-34862.

_____1993, Drinking water regulations and health advisories: U.S. Environmental Protection Agency Office of Water, 11 p.

_____1994, Summary of EPA finalized national primary drinking water regulations: U.S. Environmental Protection Agency, Region VII, 7 p.

_____1996, Drinking water regulations and health advisories: U.S. Environmental Protection Agency Office of Water, 11 p.

U.S. Environmental Protection Agency, U.S. Department of Health and Human Services, and U.S. Public Health Service, 1992, A citizens guide to radon--The guide to protecting yourself and your family from radon: U.S. Environmental Protection Agency Air and Radiation (ANR-464) 402-K92-001, May 1992.

Welch, A.H., Lico, M.S., and Hughes, J.L., 1988, Arsenic in ground water of the Western United States: Groundwater, v. 26, no. 3, p. 333-347.

Welch, A.H., Szabo, Zoltan, Parkhurst, D.L., Van Metre, P.C., and Mullin, A.H., 1995, Gross beta activity in ground water--Natural sources and artifacts of sampling and laboratory analysis: Applied Geochemistry, v. 10, p. 491-503.

Werner, S.L., Burkhardt, M.R., and DeRusseau, S.N., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of pesticides in water by Carbopak-B solid-phase extraction and high-performance liquid chromatography: U.S. Geological Survey Open-File Report 96-216, 42 p.

Williams, R.S., Jr., and Hammond, S.E., 1989, Selected water-quality characteristics and flow of ground water in the San Luis Basin, including the Conejos River subbasin, Colorado and New Mexico: U.S. Geological Survey Water-Resources Investigations Report 89-4040, 43 p.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95-181, 49 p.

Appendix 1.--Results of quality control/quality assurance samples

EXPLANATION

µS/cm, microsiemens per centimeter at 25 degrees Celsius.

deg C, degrees Celsius.

mg/L, milligrams per liter.

<, less than.

µg/L, micrograms per liter.

gross alpha, dissolved (µg/L as U-nat), dissolved gross alpha activity reported in micrograms per liter of equivalent natural uranium.

gross alpha, susp. (µg/L as U-nat), suspended gross alpha activity reported in micrograms per liter of equivalent natural uranium.

gross alpha, dissolved (pCi/L as Th-230), dissolved gross alpha activity reported in picocuries per liter as equivalent thorium-230.

gross alpha, susp. (pCi/L as Th-230), suspended gross alpha activity reported in picocuries per liter as thorium-230.

gross beta, dissolved (pCi/L as Sr-90/Y-90), dissolved gross beta activity reported in picocuries per liter as equivalent strontium-90/yttrium-90.

gross beta, susp. (pCi/L as Sr-90/Y-90), suspended gross beta activity reported in picocuries per liter as equivalent strontium-90/yttrium-90.

gross beta, dissolved (pCi/L as Cs-137), dissolved gross beta activity reported in picocuries per liter as equivalent cesium-137.

gross beta, susp. (pCi/L as Cs-137), suspended gross beta activity reported in picocuries per liter as equivalent cesium-137.

--, no data.

Appendix 1.--Results of quality control/quality assurance samples--Continued

Results of duplicate sampling

Date	pH water, whole field (standard units)	Specific conductance, lab (µS/cm)	Solids, residue at 180 deg C, dissolved (mg/L)	Alkalinity, lab (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
08-11-93	7.7	420	281	138	48	6.9	25	3.4	10	67
08-11-93	7.7	420	283	136	47	6.7	25	3.4	10	67
08-02-93	6.7	717	467	258	95	13.0	40	7.4	17	100
08-02-93	7.3	717	472	259	94	13.0	41	7.2	17	100
08-18-93	7.3	779	493	293	110	14.0	33	5.1	44	66
08-18-93	7.2	777	479	292	110	14.0	34	5.1	44	67
09-12-93	7.3	460	262	198	64	13.0	20	0.6	5.3	28
09-12-93	7.4	459	261	206	64	12.0	20	0.6	5.2	27
09-07-93	7.0	122	102	53	14	2.5	3.3	4.0	0.7	5.6
09-07-93	7.0	121	102	52	15	2.5	3.1	3.8	0.7	5.5
08-29-93	7.2	2,410	1,880	233	270	41.0	170	11	130	690
08-29-93	7.3	2,400	1,880	232	310	45.0	190	14	150	700

Appendix 1.--Results of quality control/quality assurance samples--Continued

Date	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Iron, dissolved (ug/L as Fe)
08-11-93	0.4	0.04	26	<0.01	<0.05	0.14	0.2	0.23	0.24	210
08-11-93	0.4	0.04	25	<0.01	<0.05	0.14	<0.2	0.24	0.24	210
08-02-93	0.7	0.07	22	<0.01	0.41	0.07	0.3	0.02	0.01	6
08-02-93	0.7	0.07	23	<0.01	0.43	0.07	0.3	0.02	0.01	8
08-18-93	0.5	0.12	33	<0.01	<0.05	0.09	0.2	0.03	<0.01	45
08-18-93	0.5	0.12	34	<0.01	<0.05	0.10	<0.2	0.02	0.01	43
09-12-93	1.7	0.06	14	<0.01	<0.05	0.02	<0.2	0.01	0.03	3
09-12-93	1.6	0.06	14	<0.01	<0.05	0.02	<0.2	0.01	<0.01	9
09-07-93	0.2	<0.01	32	<0.01	0.32	0.02	<0.2	0.23	0.23	55
09-07-93	0.2	<0.01	32	<0.01	0.31	0.02	<0.2	0.23	0.23	63
08-29-93	0.1	0.68	37	0.01	58.00	0.02	0.7	0.05	0.05	8
08-29-93	0.2	0.74	42	<0.01	58.00	0.03	0.6	0.05	0.04	3

Appendix 1.--Results of quality control/quality assurance samples--Continued

Date	Gross alpha, dis-solved (µg/L as U-nat)	Gross alpha, susp. (µg/L as U-nat)	Gross alpha, dis-solved (pCi/L as Th-230)	Gross alpha, susp. (pCi/L as Th-230)	Gross beta, dis-solved (pCi/L as Sr-90/ Y-90)	Gross beta, susp. (pCi/L as Sr-90/ Y-90)	Gross beta, dis-solved (pCi/L as Cs-137)	Gross beta, susp. (pCi/L as Cs-137)	Radon-222, total (pCi/L)	Carbon, organic, dis-solved (mg/L as C)
08-11-93	1.2	<0.6	1.0	<0.6	2.9	<0.6	4.0	<0.6	410	2.8
08-11-93	1.9	<0.6	1.2	<0.6	3.3	0.7	4.6	0.7	450	2.7
08-02-93	11	<0.6	8.1	<0.6	9.2	1.0	12.0	1.0	440	2.3
08-02-93	8.4	<0.6	6.1	<0.6	8.4	0.9	11.0	0.9	450	2.3
08-18-93	4.1	<0.6	2.9	<0.6	6.2	<0.6	8.3	<0.6	380	4.6
08-18-93	3.5	<0.6	2.5	<0.6	5.5	<0.6	7.4	<0.6	580	4.7
09-12-93	32	<0.6	24.0	<0.6	5.0	3.7	6.7	3.8	850	1.4
09-12-93	24	<0.6	17.0	<0.6	5.5	2.9	7.2	3.0	840	1.4
09-07-93	<0.6	<0.6	<0.6	<0.6	3.2	<0.6	3.6	<0.6	820	1.4
09-07-93	<0.6	<0.6	<0.6	<0.6	3.1	0.6	3.6	0.6	790	1.3
08-29-93	10	<0.6	82.0	<0.6	35.0	1.3	48.0	1.4	1,100	6.5
08-29-93	30	0.7	92.0	<0.6	37.0	2.3	49.0	2.4	1,100	6.2

Appendix 1.--Results of quality control/quality assurance samples--Continued

Percent recovery of group A pesticide spikes

	Date	Alpha HCH (percent recovery)	Ala-chlor (percent recovery)	Atra-zine (percent recovery)	Ben-flur-alin (percent recovery)	Butyl-ate (percent recovery)	Car-baryl (percent recovery)	Carbo-furan (percent recovery)	Chlor-pyrifos (percent recovery)	Cyana-zine (percent recovery)
Field spike	08-11-93	87	120	110	64	76	190	150	81	110
Field spike replicate	08-11-93	81	110	88	58	71	190	150	65	120
Field spike	08-02-93	82	100	100	57	75	120	120	110	120
Field spike replicate	08-02-93	84	99	100	56	76	110	120	110	120
Field spike	08-18-93	90	130	110	86	91	140	120	100	130
Field spike replicate	08-18-93	84	130	100	76	85	120	110	97	120
Field spike	09-12-93	96	100	95	68	95	69	140	93	88
Field spike replicate	09-12-93	91	94	81	63	96	53	110	87	77
Field spike	09-07-93	90	99	89	77	95	100	140	92	88
Field spike replicate	09-07-93	95	100	91	77	96	95	140	94	89
Field spike	08-29-93	110	120	110	66	110	200	200	110	150
Field spike replicate	08-29-93	110	120	110	65	110	180	180	110	120
Minimum		81	94	81	56	71	53	110	65	77
Median		90	110	100	70	90	120	140	97	120
Maximum		110	130	110	86	110	200	200	110	150

Appendix 1.--Results of quality control/quality assurance samples--Continued

	DCPA (percent recovery)	Deethyl atrazine (percent recovery)	Diazinon (percent recovery)	Dieldrin (percent recovery)	2,6-Diethyl aniline (percent recovery)	Dimethoate water (percent recovery)	Disulfoton (percent recovery)	EPTC (percent recovery)	Ethalfluralin (percent recovery)	Ethoprop (percent recovery)
Field spike	110	<20	110	91	74	26	89	72	74	110
Field spike replicate	100	<20	89	84	71	<20	74	68	64	99
Field spike	110	<20	100	89	67	33	60	70	78	93
Field spike replicate	110	<20	98	89	70	29	70	74	78	100
Field spike	120	22	110	100	79	<24	98	78	20	120
Field spike replicate	110	<20	100	110	72	<20	89	72	00	110
Field spike	110	28	99	110	100	<20	77	92	00	99
Field spike replicate	100	28	90	110	100	<20	64	93	97	89
Field spike	110	28	95	100	99	<20	62	93	73	110
Field spike replicate	110	24	98	110	100	<20	66	93	74	98
Field spike	120	35	110	93	97	24	67	98	75	110
Field spike replicate	120	29	110	90	99	22	65	100	73	110
Minimum	100	<20	89	84	67	<20	60	68	64	89
Median	110	20	100	100	97	<20	70	90	78	110
Maximum	120	35	110	110	100	33	98	100	120	120

Appendix 1.--Results of quality control/quality assurance samples--Continued

	Fonofos (percent recovery)	Lindane (percent recovery)	Lin-uron (percent recovery)	Mala-thion (percent recovery)	Methyl azin-phos (percent recovery)	Methyl para-thion (percent recovery)	Meto-lachlor (percent recovery)	Metri-buzin (percent recovery)	Mol-inate (percent recovery)	Naprop-amide (percent recovery)
Field spike	78	93	240	120	360	81	130	44	82	120
Field spike replicate	59	87	200	110	290	60	120	36	77	100
Field spike	84	98	150	93	170	68	120	41	77	120
Field spike replicate	87	91	150	92	150	69	120	35	79	110
Field spike	120	100	49	130	140	120	140	75	93	130
Field spike replicate	110	93	82	120	140	130	130	62	87	150
Field spike	86	110	110	90	89	77	110	76	95	100
Field spike replicate	79	100	100	80	78	69	98	69	95	89
Field spike	85	100	120	92	94	88	110	78	91	95
Field spike replicate	87	110	120	93	87	91	110	72	93	96
Field spike	96	110	200	110	100	83	140	72	100	110
Field spike replicate	95	110	190	110	95	84	140	69	110	100
Minimum	59	87	49	80	78	60	98	35	77	89
Median	87	100	140	100	100	81	120	62	93	100
Maximum	120	110	240	130	360	130	140	78	110	150

Appendix 1.--Results of quality control/quality assurance samples--Continued

	Para-thion (percent recovery)	Peb-ulate (percent recovery)	Pendi-meth-alin (percent recovery)	Per-methrin (percent recovery)	Phorate (percent recovery)	p,p'-DDE (percent recovery)	Pro-meton (percent recovery)	Pron-amide (percent recovery)	Propa-chlor (percent recovery)	Pro-pargite (percent recovery)
Field spike	87	75	80	17	74	71	130	94	93	240
Field spike replicate	66	71	74	18	59	69	100	86	94	200
Field spike	92	71	63	22	68	72	95	85	78	210
Field spike replicate	92	75	64	20	70	78	89	87	81	210
Field spike	180	87	97	21	94	90	500	100	120	200
Field spike replicate	170	82	98	22	95	93	480	92	110	200
Field spike	89	110	60	67	82	85	100	84	94	96
Field spike replicate	81	110	57	60	67	83	87	73	93	91
Field spike	93	110	70	77	65	82	92	88	97	100
Field spike replicate	94	110	69	70	68	84	92	87	98	90
Field spike	96	100	68	19	69	79	110	94	110	230
Field spike replicate	88	100	67	18	67	76	120	93	110	210
Minimum	66	71	57	17	59	69	87	73	78	90
Median	92	90	69	21	68	79	100	87	97	200
Maximum	180	110	98	77	95	93	500	100	120	240

Appendix 1.--Results of quality control/quality assurance samples--Continued

	Propanil (percent recovery)	Simazine (percent recovery)	Tebuthiuron (percent recovery)	Terbacil (percent recovery)	Terbufos (percent recovery)	Thiobencarb (percent recovery)	Triallate (percent recovery)	Trifluralin (percent recovery)
Field spike	110	74	96	170	72	120	95	66
Field spike replicate	98	64	94	160	65	110	87	59
Field spike	100	79	81	180	66	95	97	56
Field spike replicate	110	71	78	190	75	97	96	56
Field spike	110	110	97	72	85	99	120	90
Field spike replicate	110	100	93	70	82	91	110	80
Field spike	95	80	74	120	84	110	98	68
Field spike replicate	79	68	68	120	73	100	90	64
Field spike	100	77	82	110	75	110	96	76
Field spike replicate	100	78	78	100	77	110	97	76
Field spike	110	96	100	350	90	110	98	67
Field spike replicate	110	91	110	360	87	110	97	68
Minimum	79	64	68	70	65	91	87	56
Median	110	78	93	140	77	110	97	68
Maximum	110	110	110	360	90	120	120	90

Appendix 1.--Results of quality control/quality assurance samples--Continued

Percent recovery of volatile organic compound spikes

	Date	Bromo-form	Carbon tetra-chlo-ride	Chloro-di-bromo-methane	Di-chloro-bromo-methane	1,4,-Di-chloro-benzene	1,2-Di-chloro-ethane
Laboratory spike	08-11-93	80	60	70	74	80	87
Field spike	08-12-93	60	40	52	57	65	65
Field spike replicate	08-11-93	70	48	57	61	70	70
Laboratory spike	08-02-93	63	67	66	69	--	80
Field spike	08-02-93	60	56	61	65	--	80
Field spike replicate	08-02-93	83	60	79	70	--	80
Laboratory spike	08-18-93	90	72	78	78	95	87
Field spike	08-18-93	70	52	65	65	80	74
Field spike replicate	08-18-93	85	60	74	70	90	78
Laboratory spike	09-12-93	70	60	65	70	85	83
Field spike	09-12-93	40	36	39	43	55	52
Field spike replicate	09-12-93	60	44	57	57	75	70
Laboratory spike	09-07-93	75	60	70	74	85	87
Field spike	09-07-93	65	52	57	65	75	70
Field spike replicate	09-07-93	35	28	35	35	45	43
Laboratory spike	08-29-93	75	64	70	74	90	87
Field spike	08-29-93	60	52	61	65	75	74
Field spike replicate	08-29-93	40	32	39	39	50	48
Minimum		35	28	35	35	45	43
Median		67.5	54	63	65	75	76
Maximum		90	72	79	78	95	87

Appendix 1.--Results of quality control/quality assurance samples--Concluded

	1,1-Dichloroethylene	Ethylbenzene	Methyl-tert-butylether	Tetrachloroethylene	1,1,1-Trichloroethane	Trichloroethylene	Vinyl chloride
Laboratory spike	75	68	92	64	80	85	74
Field spike	45	52	68	44	55	60	39
Field spike replicate	50	56	76	52	60	65	35
Laboratory spike	69	66	--	67	81	76	90
Field spike	59	58	--	56	71	70	66
Field spike replicate	55	65	--	59	74	69	47
Laboratory spike	90	84	92	76	90	95	91
Field spike	60	64	72	60	70	75	43
Field spike replicate	65	76	80	64	75	80	61
Laboratory spike	75	72	88	64	80	85	87
Field spike	40	44	56	36	45	50	35
Field spike replicate	50	56	72	48	60	65	43
Laboratory spike	75	68	92	60	80	85	87
Field spike	60	60	80	52	70	75	52
Field spike replicate	35	36	44	32	40	40	35
Laboratory spike	80	72	92	64	85	90	96
Field spike	65	60	80	52	70	70	61
Field spike replicate	40	40	52	32	45	45	35
Minimum	35	36	44	32	40	40	35
Median	60	62	80	57.5	70	72.5	56.5
Maximum	90	84	92	76	90	95	96

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area

EXPLANATION

gal/min, gallons per minute.

µS/cm, microsiemens per centimeter at 25 degrees Celsius.

deg C, degrees Celsius.

--, no data.

mm of Hg, millimeters of mercury.

mg/L, milligrams per liter.

bicarbonate water dis it field (mg/L as HCO_3), bicarbonate in unfiltered sample as determined in the field by incremental titration.

alkalinity wat dis tot it field (mg/L as $CaCO_3$), alkalinity in unfiltered sample as determined in the field by incremental titration.

alkalinity wat. wh. gran t. field (mg/L as $CaCO_3$), alkalinity in unfiltered sample as determined in the field by gran titration.

nitrogen, ammonia + organic, dis (mg/L as N), dissolved ammonia plus organic nitrogen.

µg/L, micrograms per liter.

gross alpha, dissolved (µg/L as U-nat), dissolved gross alpha activity reported in micrograms per liter of equivalent natural uranium.

alpha, 2 sigma error, dissolved (µg/L as U-nat), 2 sigma precision estimate of indicated analysis.

gross alpha, susp. (µg/L as U-nat), suspended gross alpha activity reported in micrograms per liter of equivalent natural uranium.

gross alpha, dissolved (pCi/L as Th-230), dissolved gross alpha activity reported in picocuries per liter as equivalent thorium-230.

alpha, 2 sigma error, dissolved (pCi/L as Th-230), 2 sigma precision estimate of indicated analysis.

gross alpha, susp. (pCi/L as Th-230), suspended gross alpha activity reported in picocuries per liter as thorium-230.

alpha, 2 sigma error, susp. (pCi/L as Th-230), 2 sigma precision estimate of indicated analysis.

gross beta, dissolved (pCi/L as Sr-90/Y-90), dissolved gross beta activity reported in picocuries per liter as equivalent strontium-90/yttrium-90.

beta, 2 sigma error, dissolved (pCi/L as Sr-90/Y-90), 2 sigma precision estimate of indicated analysis.

gross beta, susp. (pCi/L as Sr-90/Y-90), suspended gross beta activity reported in picocuries per liter as equivalent strontium-90/yttrium-90.

beta, 2 sigma error, susp. (pCi/L as Sr-90/Y-90), 2 sigma precision estimate of indicated analysis.

gross beta, dissolved (pCi/L as Cs-137), dissolved gross beta activity reported in picocuries per liter as equivalent cesium-137.

beta, 2 sigma error, dissolved (pCi/L as Cs-137), 2 sigma precision estimate of indicated analysis.

gross beta, susp. (pCi/L as Cs-137), suspended gross beta activity reported in picocuries per liter as equivalent cesium-137.

radon-222, 2 sigma error, total (pCi/L), 2 sigma precision estimate of indicated analysis.

methyltertbutylether wat unf rec (µg/L), unfiltered sample.

srg wat flt 0.7 µg f, rec (percent), surrogate recovery in a sample filtered through a 0.7-micron-pore-size filter.

E, estimated.

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Latitude	Longitude	Date	Elevation of land-surface datum (feet above sea level)	Depth of well, total (feet)	Depth below land surface (water level) (feet)	Flow rate, instantaneous (gal/min)	Specific conductance (µS/cm)	ph water whole field (standard units)	ph water whole lab (standard units)	Temperature water (deg C)	Temperature air (deg C)
1	372849	1060902	09-08-93	7,655	15.00	6.73	0.6	398	6.85	7.0	11.5	29.2
2	373849	1061245	09-07-93	7,734	28.56	19.57	0.7	119	7.05	7.0	16.2	--
3	374153	1061532	09-15-93	7,773	34.50	19.46	0.7	199	7.05	7.3	13.0	18.7
4	374307	1061350	09-13-93	7,747	40.00	22.82	0.7	95	7.42	7.5	11.8	11.9
5	374515	1061921	09-10-93	7,735	44.80	36.31	0.5	125	8.17	7.9	12.0	18.4
6	375037	1061234	09-09-93	7,700	19.50	6.44	0.7	93	7.20	7.4	12.1	16.8
7	374757	1060853	09-09-93	7,643	17.60	4.83	0.9	595	7.37	7.3	11.2	25.1
8	374359	1060855	09-13-93	7,670	24.20	10.52	1.0	434	7.72	7.7	10.0	13.8
9	374217	1060825	09-10-93	7,671	24.75	13.10	0.8	586	7.62	7.6	12.1	25.0
10	373849	1060743	09-07-93	7,663	24.80	11.64	0.7	516	7.07	7.3	11.0	15.4
11	372732	1060504	09-08-93	7,623	14.00	4.72	0.6	857	7.66	7.5	12.9	7.1
12	371914	1060429	09-16-93	7,735	44.63	33.03	0.4	276	7.68	7.9	12.0	8.4
13	370936	1060105	09-12-93	7,782	24.85	8.77	0.6	128	7.39	7.5	15.0	24.2
14	372311	1060325	09-08-93	7,650	19.35	6.43	0.7	315	7.43	7.5	13.5	12.4
15	373323	1060250	08-26-93	7,611	19.85	9.83	0.5	541	7.39	7.2	9.8	19.4
16	374101	1060356	09-02-93	7,625	19.36	7.46	0.7	388	7.53	7.6	13.2	13.3
17	374423	1060428	08-30-93	7,624	15.89	6.69	0.5	208	7.91	7.5	14.8	12.7
18	375154	1060211	08-31-93	7,567	14.65	3.15	0.5	400	7.02	7.1	10.0	9.2
19	374825	1060213	08-31-93	7,587	19.70	9.54	0.6	198	7.80	7.8	13.9	16.3
20	374310	1060324	08-30-93	7,617	14.90	4.16	0.6	205	7.29	7.2	15.3	18.0
21	373916	1060217	08-29-93	7,613	19.70	8.25	0.6	528	7.43	7.3	13.0	24.6
22	373611	1060145	08-27-93	7,607	24.23	13.81	0.4	187	7.42	7.5	13.0	11.6
23	373242	1060045	08-26-93	7,594	18.45	2.93	0.6	1,270	7.42	7.4	8.7	22.6
24	372401	1055630	09-16-93	7,558	14.70	3.88	0.8	2,750	7.55	7.6	12.2	17.0
25	373527	1055542	08-27-93	7,570	28.56	18.17	0.5	667	7.57	7.4	11.0	12.9

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Latitude	Longitude	Date	Elevation of land-surface datum (feet above sea level)	Depth of well, total (feet)	Depth below land surface (water level) (feet)	Flow rate, instantaneous (gal/min)	Specific conductance (µS/cm)	ph water whole field (standard units)	ph water whole lab (standard units)	Temperature water (deg C)	Temperature air (deg C)
26	373754	1055752	09-02-93	7,582	19.70	10.11	0.6	839	7.43	7.5	12.0	21.7
27	374033	1055828	08-29-93	7,587	24.80	15.44	0.6	2,450	7.23	7.2	10.5	16.2
28	374431	1060007	09-01-93	7,587	17.00	7.02	0.7	977	7.42	7.5	11.6	12.0
29	374614	1060007	09-01-93	7,584	18.37	7.40	0.8	97	7.68	7.9	17.1	16.8
30	375054	1060134	08-31-93	7,568	14.40	4.42	0.7	331	7.62	7.7	13.2	20.0
31	374734	1055330	08-25-93	7,546	22.80	10.75	0.6	1,200	7.37	7.5	12.0	25.7
32	374225	1055331	08-25-93	7,557	20.00	11.40	0.8	1,170	7.61	7.7	11.7	25.9
33	374223	1055114	08-24-93	7,548	19.80	8.83	0.6	977	7.70	7.7	11.9	26.0
34	373732	1055256	08-24-93	7,558	18.50	8.30	0.7	177	7.82	7.5	13.2	15.3
35	372233	1053511	09-12-93	7,650	19.90	9.36	0.7	461	7.44	7.3	12.0	12.8

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Sodium (percent)	Potassium, dissolved (mg/L as K)	Bicarbonate water dis it field (mg/L as HCO_3)
1	580	0.5	160	47	10	19	0.7	20	3.2	162
2	581	4.5	45	14	2.5	3.3	0.2	12	4.0	62
3	575	5.6	79	27	2.7	6.2	0.3	14	3.4	108
4	569	7.4	32	11	1.2	3.7	0.3	19	2.2	48
5	580	6.7	48	16	1.9	6.6	0.4	22	2.2	70
6	579	8.0	35	11	1.9	3.9	0.3	18	3.1	48
7	578	1.0	210	63	13	28	0.8	22	8.1	152
8	570	6.6	160	54	6.2	17	0.6	18	5.2	130
9	580	6.6	240	80	10	24	0.7	17	6.7	180
10	580	4.0	220	69	11	12	0.4	10	6.7	108
11	582	0.1	280	86	15	100	3	44	2.0	244
12	577	7.3	110	34	5.9	7.4	0.3	13	1.4	28
13	568	6.2	59	19	2.7	2.5	0.1	8	1.3	74
14	578	3.0	130	42	5.9	10	0.4	14	2.6	124
15	582	4.7	230	71	13	14	0.4	11	8.1	118
16	578	4.7	160	47	10	12	0.4	13	10	96
17	578	5.6	76	24	3.9	9.9	0.5	--	<0.1	64
18	583	0.1	140	42	8.9	26	1	27	8.1	262
19	580	2.0	41	13	2.1	23	2	52	4.6	86
20	578	5.3	83	26	4.5	6.9	0.3	14	5.2	88
21	576	2.5	200	62	10	25	0.8	21	7.8	144
22	583	4.8	69	22	3.4	8.7	0.5	21	3.0	88
23	580	0.1	490	160	21	95	2	29	9.6	240
24	578	0.1	1,100	300	92	200	3	27	19	276
25	583	6.5	280	89	15	19	0.5	12	9.5	120

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Barometric pressure (mm of Hg)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Sodium (percent)	Potassium, dissolved (mg/L as K)	Bicarbonate water dis it field (mg/L as HCO_3)
26	580	2.3	220	71	11	80	2	43	10	220
27	580	5.3	840	270	41	170	3	30	11	282
28	580	2.2	260	81	14	94	3	43	12	216
29	578	0.9	24	7.6	1.2	9.0	0.8	41	3.4	52
30	582	1.2	71	22	3.8	48	2	58	4.7	184
31	579	0.1	510	160	27	72	1	23	13	451
32	580	0.5	320	97	18	140	3	48	7.6	278
33	580	0.2	200	59	13	150	5	60	11	410
34	581	0.7	25	7.5	1.5	31	3	69	4.4	100
35	575	0.4	210	64	13	20	0.6	17	0.6	258

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Alkalinity wat dis tot it field (mg/L as $CaCO_3$)	Alkalinity wat. wh. gran t. field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Solids residue at 180 deg C, dissolved (mg/L)
1	133	131	55	3.9	0.2	0.05	57	294
2	51	50	5.6	0.7	0.2	<0.01	32	102
3	89	85.6	5.9	0.5	0.1	<0.01	36	141
4	39	36.7	4.7	0.4	0.2	<0.01	30	77
5	57	56.4	4.2	0.5	0.4	<0.01	30	92
6	39	37.4	4.8	0.5	0.2	<0.01	31	75
7	125	123	39	30	0.2	0.20	40	387
8	107	105	45	5.7	0.3	0.09	31	292
9	148	147	59	4.9	0.2	0.12	33	376
10	89	89.2	85	8.6	0.1	0.10	28	354
11	200	195	250	20	0.5	0.10	45	634
12	23	21.1	92	2.5	0.3	0.02	18	175
13	61	60.0	2.4	0.5	0.1	<0.01	26	86
14	102	100	41	2.6	0.3	0.05	25	198
15	97	96.7	86	8.5	0.3	0.09	43	375
16	79	77.4	68	6.3	0.4	0.10	40	282
17	52	51.6	32	1.9	0.2	0.03	30	151
18	215	211	3.5	1.9	0.5	<0.01	43	257
19	70	69.2	16	1.3	1.0	<0.01	44	142
20	72	70.8	10	0.9	0.2	0.02	34	144
21	118	115	65	4.6	0.3	0.13	44	364
22	72	70.5	7.1	0.6	0.2	<0.01	32	113
23	197	194	340	60	0.4	0.33	50	888
24	226	226	1,100	160	0.5	0.90	64	1,960
25	98	96.5	120	69	0.1	0.43	51	423

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Alkalinity wat dis tot it field (mg/L as $CaCO_3$)	Alkalinity wat. wh. gran t. field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Solids residue at 180 deg C, dissolved (mg/L)
26	180	180	140	15	0.1	0.23	43	581
27	231	233	690	130	0.1	0.68	37	1,880
28	177	177	150	21	0.3	0.28	46	681
29	43	41.3	4.6	0.3	0.2	<0.01	37	88
30	151	149	17	1.8	2.1	0.01	58	238
31	370	364	210	42	0.2	0.36	48	750
32	228	227	260	62	0.9	0.50	51	778
33	336	332	170	19	1.2	0.23	49	694
34	82	81	9.5	1.8	1.0	<0.01	49	154
35	211	210	28	5.3	1.7	0.06	14	262

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dis (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Aluminum, dissolved (μg/L as Al)	Antimony, dissolved (μg/L as Sb)
1	0.01	2.7	0.04	<0.2	0.12	0.10	2.9	27	<1
2	<0.01	0.32	0.02	<0.2	0.23	0.23	1.4	105	<1
3	<0.01	1.4	0.03	<0.2	0.09	0.10	1.6	8	<1
4	<0.01	0.11	<0.01	<0.2	0.10	0.11	1.1	29	<1
5	<0.01	0.15	<0.01	<0.2	0.12	0.11	0.6	54	<1
6	<0.01	0.28	0.01	<0.2	0.13	0.10	0.9	57	<1
7	<0.01	22	0.02	0.4	0.09	0.07	3.2	2	<1
8	<0.01	14	0.01	0.6	0.08	0.07	1.2	7	<1
9	0.02	22	0.02	<0.2	0.09	0.08	1.4	3	<1
10	<0.01	17	0.02	<0.2	0.08	0.07	1.6	2	<1
11	<0.01	0.26	0.04	<0.2	0.11	0.10	3.0	4	<1
12	<0.01	1.4	0.02	<0.2	0.05	0.06	0.2	4	<1
13	<0.01	0.15	<0.01	<0.2	0.07	0.07	0.9	31	<1
14	<0.01	3.0	0.02	<0.2	0.12	0.09	0.8	2	<1
15	<0.01	19	0.02	0.3	0.06	0.06	2.6	3	<1
16	0.02	12	0.01	<0.2	0.16	0.16	3.1	5	<1
17	<0.01	3.7	0.02	<0.2	0.13	0.13	1.6	137	<1
18	<0.01	<0.05	0.08	0.2	0.22	0.23	1.9	6	<1
19	<0.01	1.7	<0.01	<0.2	0.14	0.15	1.7	163	<1
20	<0.01	4.1	0.03	<0.2	0.15	0.16	1.8	10	<1
21	<0.01	18	0.02	0.3	0.15	0.16	2.3	5	<1
22	<0.01	0.53	<0.01	<0.2	0.12	0.13	1.7	24	<1
23	<0.01	13	0.02	0.4	0.05	0.05	3.5	3	<1
24	0.01	8.5	0.09	0.6	0.04	0.06	5.4	4	<2
25	<0.01	2.3	<0.01	<0.2	0.04	0.04	1.5	3	<1

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dis (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Aluminum, dissolved (µg/L as Al)	Antimony, dissolved (µg/L as Sb)
26	0.02	22	0.02	0.3	0.05	0.06	1.6	3	<1
27	0.01	58	0.02	0.7	0.05	0.05	6.5	3	<1
28	0.03	34	0.04	0.5	0.09	0.10	4.6	2	<1
29	0.02	0.12	0.03	<0.2	0.11	0.11	1.6	219	<1
30	<0.01	0.17	0.02	<0.2	0.23	0.25	1.8	24	<1
31	<0.01	2.7	0.02	0.3	0.07	0.09	4.5	3	<1
32	<0.01	4.2	0.02	0.5	0.07	0.09	5.7	3	<1
33	0.03	5.9	0.02	0.5	0.14	0.16	6.1	5	<1
34	<0.01	1.1	0.01	<0.2	0.27	0.29	3.0	269	<1
35	<0.01	<0.05	0.02	<0.2	0.01	0.03	1.4	3	<1

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)
1	1	174	<1	<1	<1	<1	2	7	<1
2	2	19	<1	<1	<1	<1	2	55	<1
3	2	36	<1	<1	<1	<1	<1	6	<1
4	3	15	<1	<1	<1	<1	1	17	<1
5	5	17	<1	<1	1	<1	<1	9	<1
6	1	46	<1	<1	<1	<1	<1	34	<1
7	2	99	<1	<1	<1	<1	5	3	<1
8	3	76	<1	<1	<1	<1	1	6	<1
9	2	115	<1	<1	<1	2	2	5	<1
10	1	119	<1	<1	<1	<1	3	3	<1
11	2	146	<1	<1	<1	<1	8	4	<1
12	<1	32	<1	<1	<1	1	1	7	<1
13	1	13	<1	<1	<1	<1	<1	11	<1
14	<1	27	<1	<1	<1	<1	2	6	<1
15	3	154	<1	<1	<1	<1	2	7	<1
16	4	72	<1	<1	<1	<1	2	7	<1
17	4	35	<1	<1	5	<1	2	28	<1
18	2	170	<1	4	5	<1	4	25	<1
19	11	32	<1	<1	<1	<1	1	67	<1
20	2	51	<1	<1	<1	<1	2	8	<1
21	4	138	<1	<1	<1	<1	2	<3	<1
22	2	36	<1	<1	<1	<1	1	16	<1
23	3	66	<1	<1	<1	<1	3	<3	<1
24	2	36	<2	<2	<2	<2	7	14	<2
25	3	136	<1	<1	<1	<1	2	6	<1

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Beryl-lium, dis-solved (µg/L as Be)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Cobalt, dis-solved (µg/L as Co)	Copper, dis-solved (µg/L as Cu)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)
26	2	79	<1	<1	<1	<1	3	6	<1
27	1	25	<1	<1	1	<1	10	8	<1
28	7	165	<1	<1	<1	<1	4	13	<1
29	6	18	<1	<1	<1	<1	2	26	<1
30	17	52	<1	<1	2	<1	3	16	<1
31	3	95	<1	<1	<1	<1	5	8	<1
32	3	52	<1	<1	<1	<1	7	<3	<1
33	9	64	<1	<1	1	<1	9	4	<1
34	20	17	<1	<1	<1	<1	3	15	<1
35	<1	84	<1	<1	<1	<1	1	3	<1

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Uranium, dissolved (µg/L as U)	Zinc, dissolved (µg/L as Zn)	Gross alpha, dissolved (µg/L as U-nat)	Alpha, 2 sigma error, dissolved (µg/L as U-nat)
1	45	2	2	<1	<1	<1	2	<0.6	1.3
2	4	<1	<1	<1	<1	<1	3	<0.6	0.26
3	4	<1	<1	<1	<1	<1	4	1.6	1.0
4	<1	<1	<1	<1	<1	<1	1	<0.6	0.26
5	1	2	3	<1	<1	2	3	2.8	1.3
6	1	<1	1	<1	<1	<1	2	<0.6	0.56
7	<1	<1	2	<1	<1	3	6	4.0	2.4
8	<1	1	<1	<1	<1	5	3	6.1	2.6
9	2	2	3	<1	<1	10	5	11	4.3
10	<1	<1	3	<1	<1	3	5	5.8	3.0
11	119	5	3	<1	<1	6	3	9.2	5.6
12	13	5	<1	<1	<1	<1	2	<0.6	0.60
13	2	<1	<1	<1	<1	<1	1	<0.6	0.51
14	2	2	1	1	<1	<1	6	1.5	1.3
15	<1	2	3	<1	<1	3	5	3.5	2.4
16	1	2	<1	<1	<1	1	3	1.5	1.6
17	2	2	4	<1	<1	1	3	0.9	0.62
18	682	4	4	<1	<1	1	4	11	3.8
19	2	7	<1	<1	<1	1	5	2.0	0.89
20	<1	<1	1	<1	<1	<1	2	0.7	0.53
21	<1	2	2	1	<1	3	1	3.5	2.3
22	<1	1	1	<1	<1	<1	7	1.1	0.77
23	69	3	4	<1	<1	29	3	42	14
24	547	14	10	<1	<2	9	13	15	14
25	<1	1	2	2	<1	4	4	8.5	4.0

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Manganese, dissolved (μg/L as Mn)	Molybdenum, dissolved (μg/L as Mo)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Silver, dissolved (μg/L as Ag)	Uranium, dissolved (μg/L as U)	Zinc, dissolved (μg/L as Zn)	Gross alpha, dissolved (μg/L as U-nat)	Alpha, 2 sigma error, dissolved (μg/L as U-nat)
26	<1	1	2	1	<1	17	2	22	7.9
27	2	2	7	5	<1	81	8	110	30
28	7	7	3	3	<1	17	1	30	10
29	2	2	<1	<1	<1	<1	4	0.9	0.67
30	11	13	1	<1	<1	3	2	2.1	0.90
31	34	10	5	<1	<1	84	5	130	23
32	27	26	3	4	<1	20	2	31	11
33	195	52	4	1	<1	23	4	30	9.8
34	5	25	<1	<1	<1	<1	3	1.6	1.1
35	72	6	2	<1	<1	26	5	32	6.1

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Gross alpha, susp. (µg/L as U-nat)	Gross alpha, dis-solved (pCi/L as Th-230)	Alpha, 2 sigma error, dissolved (pCi/L as Th-230)	Gross alpha, susp. (pCi/L as Th-230)	Alpha, 2 sigma error, susp. (pCi/L as Th-230)	Gross beta, dis-solved (pCi/L as Sr-90/ Y-90)	Beta, 2 sigma error, dissolved (pCi/L as Sr-90/ Y-90)	Gross beta, susp. (pCi/L as Sr-90/ Y-90)
1	3.6	<0.6	0.81	3.6	2.2	2.6	0.7	3.0
2	<0.6	<0.6	0.18	<0.6	0.19	3.2	0.76	<0.6
3	<0.6	1.1	0.71	<0.6	0.21	3.1	0.76	0.7
4	<0.6	<0.6	0.18	<0.6	0.19	2.4	0.73	0.6
5	<0.6	1.7	0.84	<0.6	0.57	2.1	0.64	1.5
6	<0.6	<0.6	0.39	<0.6	0.31	2.5	0.70	<0.6
7	<0.6	2.9	1.7	<0.6	0.29	6.9	1.4	<0.6
8	<0.6	4.4	1.8	<0.6	0.16	6.9	1.3	0.7
9	<0.6	7.0	2.8	<0.6	0.14	9.6	1.6	1.0
10	<0.6	4.4	2.3	<0.6	0.21	5.7	1.2	<0.6
11	0.8	6.6	4.0	1.1	0.81	2.4	0.98	2.1
12	<0.6	<0.6	0.43	<0.6	0.19	1.3	0.54	<0.6
13	<0.6	<0.6	0.37	<0.6	0.28	1.4	0.57	<0.6
14	<0.6	0.9	0.85	<0.6	0.21	2.3	0.87	<0.6
15	<0.6	2.7	1.8	<0.6	0.21	7.7	1.4	<0.6
16	<0.6	1.1	1.2	<0.6	0.31	8.8	1.5	<0.6
17	<0.6	0.7	0.44	<0.6	0.34	4.4	0.92	1.1
18	0.8	8.1	2.7	<0.6	0.43	6.7	1.3	<0.6
19	<0.6	1.4	0.63	<0.6	0.38	4.2	0.89	1.3
20	<0.6	<0.6	0.37	<0.6	0.22	4.9	0.99	0.7
21	<0.6	2.5	1.7	<0.6	0.28	8.3	1.5	0.8
22	<0.6	0.7	0.49	<0.6	0.33	3.4	0.8	0.8
23	<0.6	27	8.7	<0.6	0.23	14	2.6	1.7
24	<0.6	11	10	<0.6	0.20	33	6.3	0.8
25	<0.6	5.9	2.8	<0.6	0.30	11	1.8	1.0

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Gross alpha, susp. (μg/L as U-nat)	Gross alpha, dis-solved (pCi/L as Th-230)	Alpha, 2 sigma error, dissolved (pCi/L as Th-230)	Gross alpha, susp. (pCi/L as Th-230)	Alpha, 2 sigma error, susp. (pCi/L as Th-230)	Gross beta, dis-solved (pCi/L as Sr-90/ Y-90)	Beta, 2 sigma error, dissolved (pCi/L as Sr-90/ Y-90)	Gross beta, susp. (pCi/L as Sr-90/ Y-90)
26	<0.6	17	6.0	<0.6	0.29	13	2.2	1.1
27	<0.6	82	22	<0.6	0.23	35	6.3	1.3
28	<0.6	19	6.6	<0.6	0.18	12	2.2	1.6
29	0.9	<0.6	0.42	0.7	0.55	3.0	0.74	0.8
30	<0.6	1.4	0.63	<0.6	0.20	4.5	0.97	1.5
31	<0.6	89	16	<0.6	0.20	32	4.7	3.3
32	<0.6	22	7.6	<0.6	0.13	15	2.7	1.5
33	<0.6	22	7.3	<0.6	0.23	13	2.5	1.4
34	2.9	1.1	0.75	3.9	1.9	3.3	0.82	2.6
35	<0.6	24	4.6	<0.6	0.18	5.0	1.1	3.7

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Beta, 2 sigma error, susp. (pCi/L as Sr-90/ Y-90)	Gross beta, dis-solved (pCi/L as Cs-137)	Beta, 2 sigma error, dissolved (pCi/L as Cs-137)	Gross beta, susp. (pCi/L as Cs-137)	Radon-222, total (pCi/L)	Radon-222 2 sigma error, total (pCi/L)	p,p'-DDE, dissolved (μg/L)	Meto-lachlor water, dissolved (μg/L)
1	0.93	3.4	0.97	3.2	1,800	59	<0.006	<0.002
2	0.51	3.6	0.87	<0.6	820	53	<0.006	<0.002
3	0.57	4.0	1.1	0.7	1,500	46	<0.006	<0.002
4	0.59	2.8	0.90	0.7	1,500	43	<0.006	<0.002
5	0.70	2.5	0.88	1.5	--	--	<0.006	<0.002
6	0.52	2.9	0.96	<0.6	--	--	<0.006	<0.002
7	0.52	9.1	1.8	<0.6	--	--	<0.006	<0.002
8	0.54	9.0	1.6	0.8	1,300	41	<0.006	<0.002
9	0.57	13	2.2	1.0	--	--	<0.006	0.072
10	0.52	7.6	1.5	<0.6	1,500	57	<0.006	<0.002
11	0.76	3.2	1.3	2.2	1,300	57	<0.006	<0.002
12	0.46	1.7	0.75	<0.6	1,900	44	<0.006	<0.002
13	0.56	1.6	0.69	<0.6	930	44	E0.002	<0.002
14	0.49	3.0	1.0	<0.6	1,400	56	<0.006	<0.002
15	0.54	10	1.8	<0.6	1,600	42	<0.006	<0.002
16	0.48	11	1.9	<0.6	1,100	45	<0.006	<0.002
17	0.61	5.3	1.1	1.1	1,900	55	<0.006	<0.002
18	0.46	9.0	1.7	<0.6	930	55	<0.006	<0.002
19	0.63	5.1	1.1	1.4	1,400	55	<0.006	<0.002
20	0.55	6.1	1.2	0.8	1,100	49	<0.006	<0.002
21	0.56	11	1.9	0.8	1,400	49	<0.006	<0.002
22	0.51	4.3	1.2	0.8	--	--	<0.006	<0.002
23	0.67	18	3.6	1.7	1,100	40	<0.006	<0.002
24	0.65	43	8.3	0.9	700	36	<0.006	<0.002
25	0.66	14	2.5	1.1	--	--	<0.006	<0.002

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

Map reference number (fig. 3)	Beta, 2 sigma error, susp. (pCi/L as Sr-90/ Y-90)	Gross beta, dis- solved (pCi/L as Cs-137)	Beta, 2 sigma error, dissolved (pCi/L as Cs-137)	Gross beta, susp. (pCi/L as Cs-137)	Radon-222, total (pCi/L)	Radon-222 2 sigma error, total (pCi/L)	p,p'-DDE, dissolved (µg/L)	Meto-lachlor water, dissolved (µg/L)
26	0.61	17	2.9	1.1	1,300	46	<0.006	<0.002
27	0.69	48	8.5	1.4	1,100	48	<0.006	<0.002
28	0.68	17	3.0	1.6	1,500	54	<0.006	<0.002
29	0.57	3.4	0.84	0.8	1,200	52	<0.006	<0.002
30	0.65	5.9	1.3	1.6	1,100	50	<0.006	<0.002
31	0.88	42	6.3	3.4	1,000	44	<0.006	<0.002
32	0.66	20	3.6	1.6	920	44	<0.006	<0.002
33	0.65	18	3.4	1.5	920	45	<0.006	<0.002
34	0.83	4.3	1.3	2.8	1,400	49	<0.006	<0.002
35	0.94	6.7	1.4	3.8	850	44	<0.006	<0.002

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Continued

				Group A pesticide surrogates			Group B pesticide surrogate
Map reference number (fig. 3)	Metri-buzin water, dis-solved (µg/L)	Methyl-tert-butyl-ether wat unf rec (µg/L)	Pro-meton water, dis-solved (µg/L)	Diaz-inon srg wat flt 0.7 µg f, rec (percent)	Terbuth-ylazine srg wat flt 0.7 µg f, rec (percent)	HCH alpha srg wat flt 0.7 µg f, rec (percent)	BDMC, srg wat flt 0.7 µg f, rec (percent)
1	<0.004	<0.2	<0.018	100	100	100	32
2	<0.004	<0.2	<0.018	90	100	100	46
3	<0.004	<0.2	<0.018	80	93	100	1.0
4	<0.004	<0.2	<0.018	80	95	100	18
5	<0.004	<0.2	<0.018	80	93	90	64
6	<0.004	<0.2	<0.018	90	93	90	50
7	<0.004	<0.2	<0.018	90	88	90	48
8	<0.004	<0.2	<0.018	80	96	100	12
9	0.01	<0.2	<0.018	80	93	90	44
10	E0.005	0.6	<0.018	90	96	90	32
11	<0.004	<0.2	<0.018	80	84	90	30
12	<0.004	<0.2	<0.018	80	95	100	52
13	<0.004	<0.2	<0.018	90	89	90	54
14	<0.004	<0.2	<0.018	90	90	90	56
15	<0.004	<0.2	<0.018	70	100	80	51
16	0.017	<0.2	<0.018	80	92	80	76
17	<0.004	<0.2	<0.018	100	110	100	68
18	<0.004	<0.2	<0.018	90	110	90	48
19	<0.004	<0.2	0.01	100	120	100	60
20	<0.004	<0.2	<0.018	100	120	100	38

Appendix 2.--Data for shallow ground water in the San Luis Valley land-use study area--Concluded

				Group A pesticide surrogates			Group B pesticide surrogate
Map reference number (fig. 3)	Metri- buzin water, dis- solved (µg/L)	Methyl- tert- butyl- ether wat unf rec (µg/L)	Pro- meton water, dis- solved (µg/L)	Diaz- inon srg wat flt 0.7 µg f, rec (percent)	Terbuth- ylazine srg wat flt 0.7 µg f, rec (percent)	HCH alpha srg wat flt 0.7 µg f, rec (percent)	BDMC, srg wat flt 0.7 µg f, rec (percent)
21	<0.004	<0.2	<0.018	90	110	100	48
22	<0.004	<0.2	<0.018	90	110	100	56
23	<0.004	<0.2	<0.018	70	110	80	0
24	<0.004	<0.2	<0.018	80	97	100	52
25	<0.004	<0.2	<0.018	90	120	100	48
26	<0.004	<0.2	<0.018	80	90	80	58
27	<0.004	<0.2	<0.018	80	120	100	0
28	<0.004	<0.2	<0.018	80	94	80	64
29	<0.004	<0.2	<0.018	80	95	80	65
30	<0.004	<0.2	<0.018	100	110	90	42
31	<0.004	<0.2	<0.018	70	93	80	52
32	<0.004	<0.2	<0.018	70	90	80	41
33	<0.004	<0.2	<0.018	70	94	80	20
34	<0.004	<0.2	<0.018	80	96	90	20
35	<0.004	<0.2	<0.018	90	94	90	0