WATER-QUALITY ASSESSMENT AND MAPPING FOR THE PRINCIPAL VALLEY-FILL AQUIFER IN SANPETE VALLEY, SANPETE COUNTY, UTAH

by
Mike Lowe, Janae Wallace, and Charles E. Bishop

Aerial photograph of Sanpete Valley, Sanpete County, Utah. View is to the north and shows west-dipping rocks of the Wasatch Plateau on the eastern margin of the valley (photograph by Doug Sprinkel, Utah Geological Survey).

SPECIAL STUDY 102
UTAH GEOLOGICAL SURVEY
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UTAH DEPARTMENT OF NATURAL RESOURCES

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ABSTRACT

Sanpete Valley (herein including Arapien Valley) is a rural area located in central Utah; the unconsolidated valley-fill aquifer is the principal source of drinking water in this valley. In cooperation with the Utah Division of Water Quality and the U.S. Environmental Protection Agency, we assessed water quality in the valley-fill aquifer to: (1) classify ground-water quality according to Utah Water Quality Board standards, (2) determine the relationship of ground-water quality to geologic units in the San Pitch River drainage basin, (3) determine likely sources of nitrate pollution documented in previous investigations, and (4) assess the potential for downgradient degradation of water quality from high-nitrate wells.

We collected and analyzed ground-water samples from 443 water wells and surface-water samples from two ponds during the summer and autumn of 1996 and spring of 1997 to evaluate total-dissolved-solids and nitrate concentrations. Wells were selected based on their location (representing a widespread geographic distribution, but without bias regarding land use) and discrete perforated-interval depths within the valley-fill aquifer. To identify a possible correlation between water quality and depth, we selected wells from three depth intervals: shallow wells, less than 100 feet (30 m); medium-depth wells, 100 to less than 200 feet (30-61 m); and deep wells, 200 feet (61 m) and greater. Ground water from all sample locations was analyzed for the nutrients nitrate, nitrite, ammonia, and phosphate. Of the 443 wells, ground water from 118 wells was tested for general chemistry, 107 for dissolved metals, and 49 for organics and pesticides. Ground water from some of these wells was resampled and analyzed for nitrate in 1997 and 1999 to determine if there were any temporal changes in concentrations. Ground water from three high-nitrate wells was analyzed for tritium in 2000.

Total-dissolved-solids concentrations for wells tested for general chemistry range from 234 to 2,752 mg/L. By area, 66.5 percent of the aquifer is classified as class 1A (Pristine), 32 percent is classified as class 2 (Drinking Water Quality), and about 1.5 percent is classified as class 3 (Limited Use). Elevated levels of total-dissolved-solids concentrations in ground water are largely attributed to proximity to outcrops of the Arapien Shale and the Green River Formation.

The average nitrate concentration for ground water in the valley-fill aquifer is 3.3 mg/L. Of the water wells analyzed for nitrate, 86.5 percent yielded values less than 5 mg/L, and only 3.5 percent exceeded Utah drinking-water standards for nitrate (greater than 10 mg/L) and are considered high-nitrate wells. At least half of the high-nitrate wells may be isolated single-well contaminations. However, a paucity of data points near these isolated high-nitrate wells precludes a plume/non-plume interpretation; installation of monitoring wells downgradient from the high-nitrate wells will be necessary to make such an interpretation. Most of the high-nitrate wells are less than 150 feet (46 m) deep and/or in primary recharge areas. Potential nitrogen sources associated with the high-nitrate wells varies from well to well, and includes septic-tank systems, agricultural fertilizer, and animal-waste products.

Utah drinking-water standards were exceeded for lead in two wells, arsenic in two other wells, and copper in another well. Of the 49 water wells tested for pesticides, seven wells yielded water having values above the detection limit, but below Utah drinking-water standards. Tritium analysis of ground water from three high-nitrate wells indicates that contaminated ground water was recharged during the early- to mid-1960s when tritium concentrations in the atmosphere were at their peak levels.

We used the GMS ground-water modeling system, applied to a regional, three-dimensional, steady-state MODFLOW model, to determine ground-water flow directions in the Sanpete Valley portion of the study area. Particle tracking of nitrate contamination was accomplished using the results of the regional ground-water flow model and an estimated effective porosity distribution. This allowed us to simulate ground-water flow paths and calculate particle travel times to and from contaminated wells. Simulated reverse particle locations, computed from the results of the modeling, indicate that ground-water flow rates near the contaminated wells range from 7 to 200 feet per year (2-61 m/yr), indicating that contamination sources are likely within about 1.5 miles (2.4 km) of the high-nitrate wells.

INTRODUCTION

Background

Sanpete Valley (figure 1) is a rural area where most residential development and agricultural activities are on uncon-

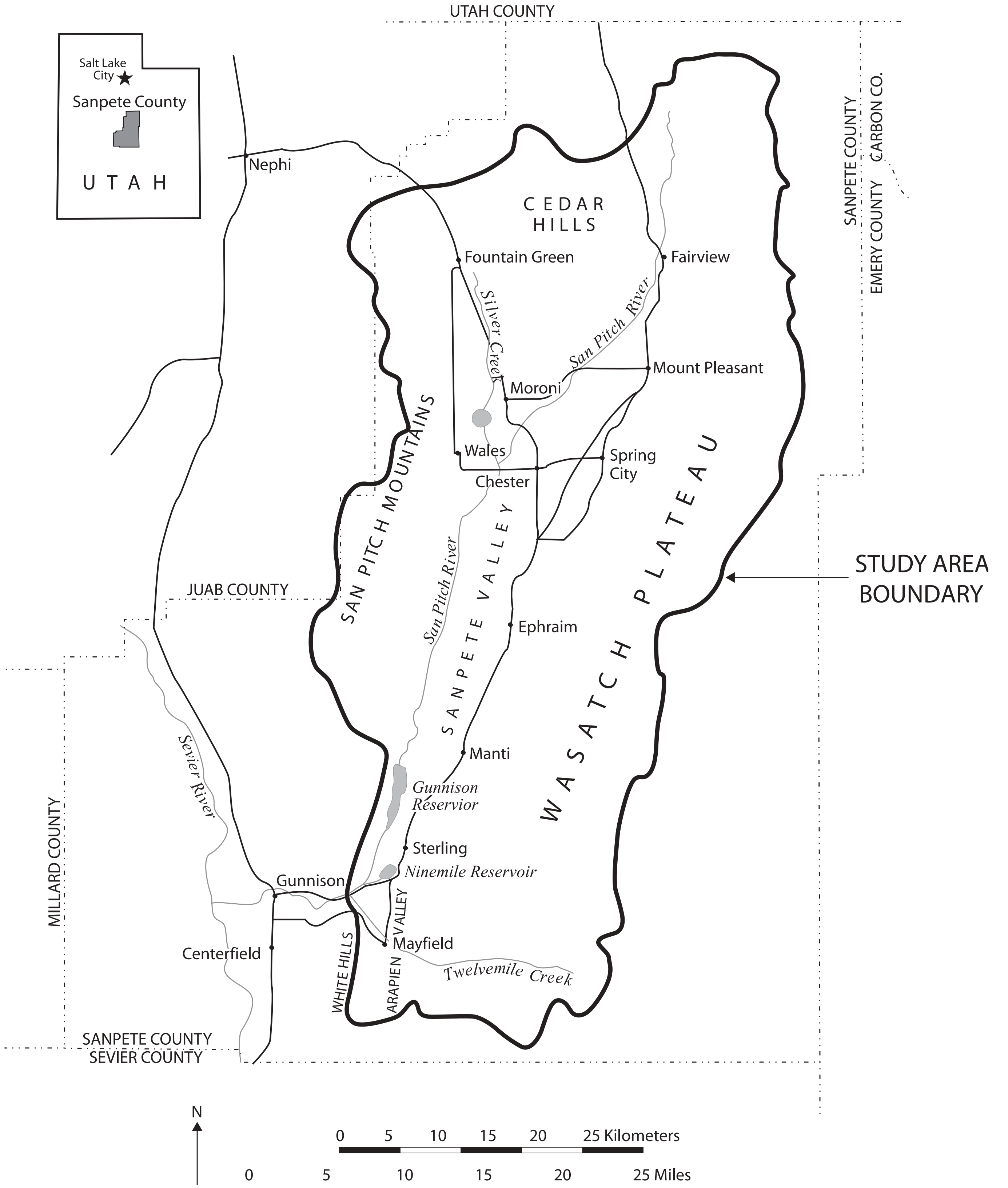


Figure 1. *Sanpete Valley, Sanpete County, Utah study area.*

solidated valley-fill deposits, which are the principal drinking-water aquifer for the area. In this study, we follow the Sanpete County Planning Commission (1997) and include the Arapien Valley to the south as part of the Sanpete Valley study area (figure 1). Many residents use septic tank soil-absorption systems for wastewater treatment. Septic-tank effluent, agricultural fertilizers, and animal wastes from feed lots and turkey farms are potential sources of nitrate, the principal ground-water contaminant identified during previous ground-water studies in the area (Robinson, 1968; Horns, 1995). High nitrate levels in ground water have been documented in Sanpete Valley, where many wells have historically yielded ground water with greater than 40 mg/L nitrate (Robinson, 1968; Horns, 1995). Ground water from a city well in Moroni exceeded the Utah drinking-water standard of 10 mg/L for nitrate during the fall of 1994 (Horns, 1995), and the well was ultimately taken off line. Ground water from another city well in Manti contains about 4.5 mg/L nitrate (Snyder and Lowe, 1998). These incidents of relatively high nitrate concentrations reported in public-supply wells prompted this study to evaluate the water quality in Sanpete Valley.

The valley-fill aquifer is the principal source of drinking water for residents of Sanpete Valley, although springs along the valley margins are also used as a drinking-water source. Preservation of good ground-water quality is a critical issue for land-use planning and resource management in Sanpete County. Local government officials in Sanpete County have expressed concern about the impact of nitrate contamination on ground-water resources, especially public water-supply wells. Utah Division of Water Quality regulators would like to understand the relationship between geology and water quality so that they can better implement their Watershed Protection Program, and utilize best management practices to reduce contamination, especially from nitrate.

Purpose and Scope

State and local government officials and water users in Sanpete Valley need ground-water quality information to help them make informed decisions on land use to protect ground-water resources. The purpose of this study, a cooperative effort among the Utah Geological Survey (UGS), the Utah Division of Water Quality, and the U.S. Environmental Protection Agency, is to provide local government officials, state agencies, and private water users with: (1) maps showing total-dissolved-solids concentrations, nitrate concentrations, and ground-water quality classes for the principal valley-fill aquifer, (2) a determination of the relationship between drainage-basin geology and ground-water quality, (3) an identification of all likely sources of nitrate contamination, and (4) an evaluation of transport and fate of nitrate in Sanpete Valley.

Local government officials can use the data, maps, and information from this study to:

(1) help protect drinking-water sources through the implementation of best management practices under the Utah Division of Water Quality's Watershed Protection Program,
(2) prioritize sources of nitrate contamination for remediation,
(3) regulate on-site wastewater disposal-system density through more effective zoning practices,
(4) help determine the best locations for sanitary landfills and feed lots,
(5) improve fertilizer- and pesticide-application practices through education/awareness,
(6) determine where public water and sewer systems would be more prudent than private water and wastewater-disposal systems, and
(7) facilitate aquifer vulnerability/sensitivity studies, drinking-water-source- (wellhead) protection-area delineation, and classification of water quality under the Utah Water Quality Board's ground-water quality classification system.

The scope of work included:

(1) conducting a water-well inventory to identify wells for valley-wide sampling within shallow (less than 100 feet [33 m]), medium (100 to less than 200 feet [33-66 m]), and deep (200 feet [66 m] and greater) perforation-depth categories,
(2) collecting water samples for water-chemistry analysis (nutrients, general chemistry, and organics),
(3) mapping total-dissolved-solids and nitrate concentrations,
(4) compiling geologic maps for use in identifying potential geologic factors contributing to water-quality degradation in areas with high total-dissolved-solids concentrations,
(5) examining wells with water exceeding 10 mg/L nitrate concentration to evaluate well condition and identify potential sources of nitrate,
(6) selecting additional wells in the vicinity of wells with water exceeding 10 mg/L nitrate concentration to help determine the source and extent of nitrate contamination,
(7) resampling of wells with water exceeding 7 mg/L nitrate concentration (high-nitrate wells) to determine temporal variations in nitrate concentration,
(8) mapping potential ground-water contamination sources in Sanpete Valley for ground-water quality classification purposes, and for determining relationships, if any, between land-use practices and high-nitrate wells,
(9) using the GMS ground-water modeling system, applied to a regional, three-dimensional, steady-state MODFLOW model of Sanpete Valley, to determine ground-water flow directions,
(10) using the GMS ground-water modeling system for particle tracking of nitrate contamination, determining ground-water flow paths, and calculating particle travel times to and from contaminated wells for evaluating fate and transport of nitrate contamination and evaluating potential sources of nitrate contamination,
(11) evaluating water chemistry in areas having multiple high-nitrate wells to determine the likelihood of extensive nitrate contamination (plumes),
(12) producing maps showing nitrate concentration for each perforated-depth category and ground-water recharge areas,
(13) sampling ground water from selected high-nitrate wells and analyzing for tritium to help constrain the age of contaminated water,
(14) producing a map showing ground-water quality classes under the Utah Water Quality Board classification system for the valley-fill aquifer, and
(15) preparing this report summarizing the findings.

Methods

Water-Well Sampling

We selected 443 wells (plate 1) for sampling from four depth categories: (1) 147 shallow wells (less than 100 feet [30 m] deep), (2) 218 medium-depth wells (100 to less than 200 feet [30-<61 m]), and (3) 71 deep wells (200 feet [61 m] deep and greater), all completed in the principal aquifer; and (4) seven wells of unknown depth but presumed to be completed in the principal aquifer. Two ponds representative of water in the shallow unconfined aquifer were also sampled. The wells and ponds were sampled during summer/fall of 1996 and spring/summer of 1997, and the water was analyzed for nutrients (nitrate, nitrite, ammonia, and phosphorous) content by the Utah Division of Epidemiology and Laboratory Services. The UGS resampled high-nitrate-concentration wells (greater than 7 mg/L) during fall of 1999, three of which were sampled for tritium during summer of 2000. Of these 443 wells, water from 118 wells was analyzed for general chemistry, 107 wells for metals, and 49 wells for organics and pesticides. The constituents sampled for, the U.S. Environmental Protection Agency (EPA) analysis method, and ground-water quality standard (if the constituent has been assigned one) are provided in table 1. All of the wells and ponds were sampled by the Utah Division of Water Quality, except the high-nitrate-concentration wells resampled in 1999 and the wells sampled for tritium in 2000. Sixteen of the high-nitrate-concentration wells were field checked by various agencies to determine potential source(s) of nitrate (including the local Utah State University Agricultural Extension Service agent, and employees from the Utah Division of Water Quality, Utah Geological Survey, and Utah Department of Agriculture).

Land-Use Mapping

We mapped potential ground-water contaminant sources including facilities related to mining, manufacturing, agricultural practices, and wastewater-treatment facilities (plate 2; appendix A). A primary objective was to identify all potential pollutant sources to establish a relationship between water quality and land-use practices, emphasizing those that may be sources of nitrate. We mapped approximately 940 potential contaminant sources for the valley-fill aquifer in the following categories in Sanpete Valley:

(1) mining, which includes abandoned and active gravel mining operations and borrow pits,
(2) agricultural practices, which consist of irrigated and non-irrigated farms, active and abandoned animal feed lots, corrals, and stables/barnyards,
(3) animal wastes that are dominantly produced from feeding facilities, waste transported by runoff, and excrement on grazing or pasture land that potentially contribute nitrate,
(4) industrial wastes that potentially contribute pesticides, metals, solvents, petroleum products, and PCB spills associated with a variety of sources such as salt production/storage facilities, transportation facilities, transformer stations, and excavating facilities,
(5) small businesses, such as laundromats, beauty parlors, and dry cleaners, some of which may contribute pollutants, such as solvents, into the ground-water system,
(6) large lawns, including parks, cemeteries, and nurseries that may contribute fertilizer and pesticides,
(7) service stations including auto shops and gas stations that may contribute fuel, oil, antifreeze, and solvents; junkyard/salvage operations that may contribute pollutants such as metals and solvents,
(8) waste-disposal sites that may contribute pollutants such as solvents, metals, and nitrate,
(9) storage tanks that may contribute pollutants such as fuel and oil, and
(10) medical facilities, including dental, health clinics, pharmaceutical, and veterinarian services, that may contribute pollutants such as metals and solvents.

Well Numbering System

The numbering system for wells in this study is based on the Federal Government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian (figure 2). The study area is entirely within the southeastern quadrant (D). The wells are numbered with this quadrant letter D, followed by township and range, enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section designated by letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (D-16-3)9adb-1 is the first well in the northwest quarter of the southeastern quarter of the northeastern quarter of section 9, Township 16 South, Range 3 East (NW1/4SE1/4NE1/4 section 9, T. 16 S, R. 3 E).

Location and Geography

Sanpete and Arapien Valleys are in central and south-central Sanpete County (figure 1), central Utah, about 90 miles (150 km) south of Salt Lake City. Sanpete Valley is a north-south-trending, Y-shaped valley bordered on the east by the Wasatch Plateau, which reaches elevations at the drainage divide of more than 11,000 feet (3,350 m), and on the west by the San Pitch Mountains (also known as the Gunnison Plateau), which reach a maximum elevation of about 9,700 feet (3,000 m) in northeastern Sanpete County. The valley is divided in the north by the Cedar Hills, which form the center of the Y and reach a maximum elevation of about 8,300 feet (2,530 m). Sanpete Valley is about 40 miles (60 km) long and up to 13 miles (21 km) wide. The valley floor has an area of about 240 square miles (620 km2); it ranges in elevation from 7,400 feet (2,560 m) near the northern end of the eastern arm and 6,300 feet (1920 m) at the northern end of the western arm to about 5,240 feet (1,600 m) in the southeastern end of the study area about 2 miles (3.2 km) southeast of Ninemile Reservoir.

Arapien Valley is south of Sanpete Valley (figure 1) and ranges in elevation from about 5,600 feet (1,700 m) in the east to about 5,400 feet (1,650 m) in the west. Arapien Valley is 8 miles (13 km) long and 1 mile (1.6 km) wide, and is separated from Sanpete Valley by a low divide located about 1 mile (1.6 km) south of Ninemile Reservoir. Arapien Valley, bound by the Wasatch Plateau on the east and the White

Table 1. *EPA primary ground-water quality standards and analytical method for some chemical constituents sampled in Sanpete Valley, Sanpete County, Utah.*

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD	GROUND-WATER QUALITY STANDARD (mg/L)
total dissolved solids	160.1	2000+** (or 500*++)
total nitrate/nitrite	353.2	10.0
ammonia as nitrogen	350.3	-
arsenic	200.9	0.05
barium	200.7	2.0
cadmium	200.9	0.005
chromium	200.9	0.1
copper	200.7	1.3
lead	200.9	0.015
mercury	245.1	0.002
selenium	200.9	0.05
silver	200.9	0.1
zinc	200.7	5.0
aluminum*	200.7	0.05 to 0.2
calcium*	200.7	-
sodium*	200.7	-
bicarbonate	406C	-
carbon dioxide	406C	-
carbonate	406C	-
chloride*	407A	250
total alkalinity	310.1	-
total hardness	314A	-
specific conductance	120.1	-
iron*	200.7	0.3
potassium*	200.7	-
hydroxide	406C	-
sulfate *++	375.2	250
magnesium*	200.7	-
manganese*	200.7	0.5
total phosphorous and dissolved total phosphate	365.1	-
aldicarb	531.1	0.003
aldicarb sulfoxide	531.1	0.004
atrazine	525.2	0.003
carbofuran	531.1	0.04
2, 4-D	515.1	0.07
methoxychlor	525.2	0.4
methiocarb	531.1	-
dinoseb	515.1	0.007
dalapon	515.1	0.2
baygon	515.1	-
picloram	515.1	0.5
dicamba	515.1	-
2-4-5-T	515.1	-
oxamyl	531.1	0.2
methomyl	531.1	-
carbaryl	531.1	-
3-Hydroxycarbofuran	531.1	-
dichlorprop	515.1	0.005
pentachlorophenol	515.1	0.001
2, 4, 5-TP	515.1	0.05
pH	150.1	must be between 6.5 and 8.5

* for secondary standards only (iron, for example, exceeding these concentrations does not pose a health threat)
+ maximum contaminant level is reported from the Utah Administrative Code R309-103 (Utah Division of Water Quality)
** For public water-supply wells, if TDS is greater than 1000 mg/l, the supplier shall satisfactorily demonstrate to the Utah Water Quality Board that no better water is available. The Board shall not allow the use of an inferior source of water if a better source of water (i.e., lower in TDS) is available
++ TDS and Sulfate levels are given in the Primary Drinking Water Standards, R309-103- 2.1. They are listed as secondary standards because levels in excess of these recommended levels will likely cause consumer complaint

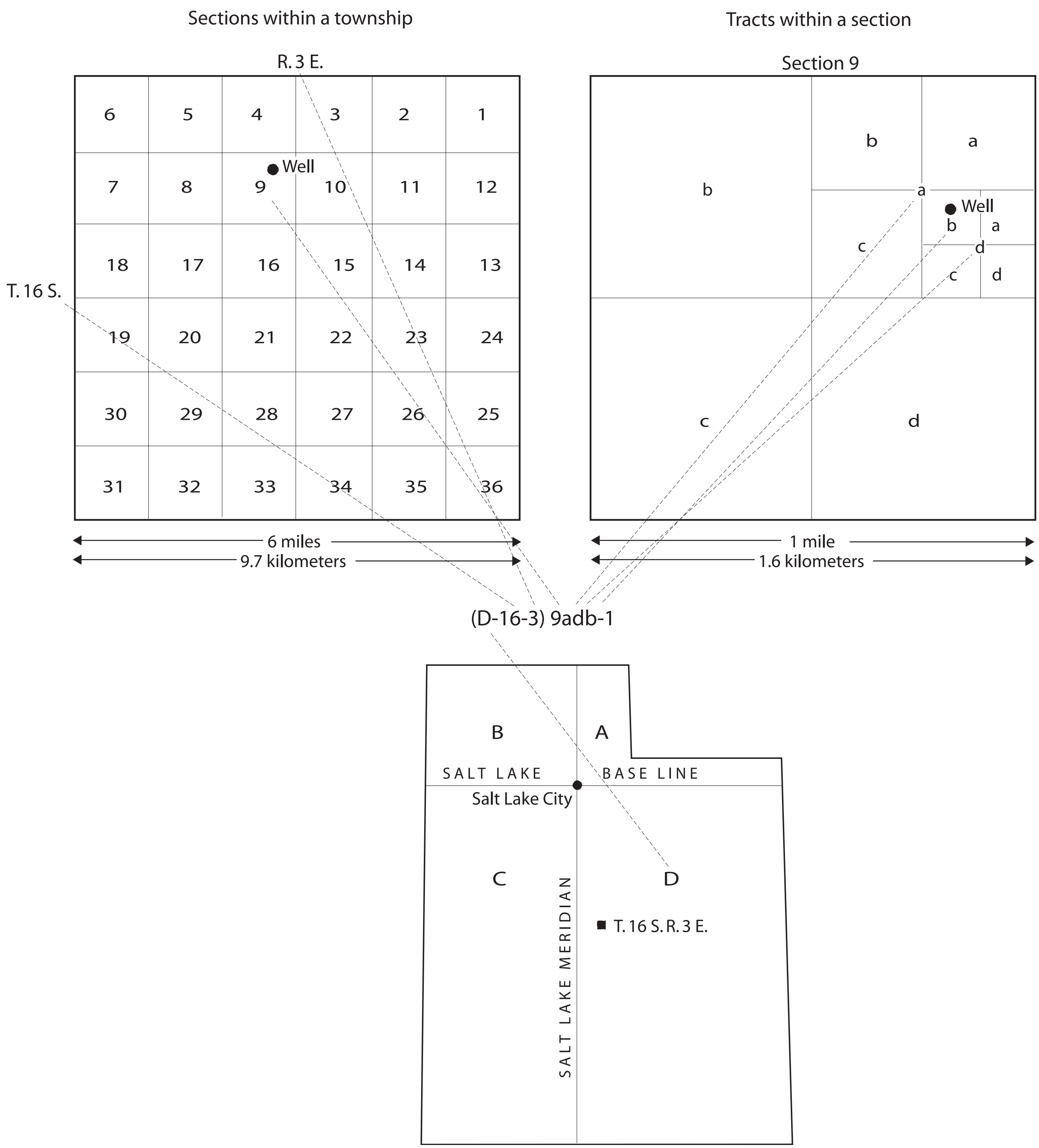


Figure 2. *Numbering system for wells in Utah (see text for additional explanation).*

Hills on the west, is separated from the central Sevier River basin at its southernmost point by a low divide about 4 miles (6.4 km) south of Mayfield.

Surface Water

The study area includes most of the 600 square-mile (1,500 km^2) San Pitch River watershed in Sanpete County (figure 1). The headwaters of the San Pitch River, the largest tributary of the Sevier River (Woolley, 1947), are in the eastern arm of Sanpete Valley. South of Moroni, the San Pitch River is joined by Silver Creek, an intermittent stream that drains the western arm of the valley. Table 2 lists the major tributaries to the San Pitch River and their drainage basin areas. The San Pitch River flows south through Sanpete Valley to Gunnison Reservoir, where the valley narrows, and then into the Sevier River west of Gunnison, Utah. Table 3 lists the surface-water reservoirs in the Sanpete Valley and their capacity. Inflow to the San Pitch River from tributaries is estimated to be 15,000 acre-feet per year (18.5 hm^3/yr) from the Cedar Hills and San Pitch Mountains, and 137,000 acre-feet per year (169 hm^3/yr) from the Wasatch Plateau, for a total of 152,000 acre-feet per year (187 hm^3/yr) (Wilberg and Heilweil, 1995).

Arapien Valley includes the drainage of Twelvemile Creek, which flows west from the Wasatch Plateau and into the San Pitch River about 2 miles (3.2 km) southwest of Ninemile Reservoir (figure 1). Inflow to Twelvemile Creek from the Wasatch Plateau averaged 21,400 acre-feet per year (26 hm^3/yr) between 1960 and 1980 (William E. Schlotthauer, Utah Division of Water Rights, written communication, October 2, 2000).

Approximately 11,000 acre-feet per year (13.6 hm^3/yr) of water from the Colorado River Basin is brought into the San Pitch River drainage basin via 13 tunnels and ditches (Wilberg and Heilweil, 1995). Major transbasin diversions include the Ephraim, Fairview, Manti, and Spring City tunnels (for locations see topographic base for plate 3); some of this water is from Fairview Lakes and Lower Gooseberry Reservoir (Wilberg and Heilweil, 1995).

Population and Land Use

Sanpete Valley is a rural area experiencing moderate population growth resulting in increased residential development; much of the existing and future development uses septic tank soil-absorption systems for wastewater disposal, though some areas are connected to sewer and maintain sewage lagoons (plate 2). Sanpete County had a 1990 Census population of 16,259 (Utah Division of Water Resources, 1999); its 1999 Census population was 21,408 (Utah League of Cities and Towns, 2000). Population is projected to grow another 1 percent annually over the next 20 years; by 2020 the population of Sanpete County is expected to reach 28,177 (Demographic and Economic Analysis Section, 2000).

Government and non-farm proprietors (private business owners) have provided the most employment in Sanpete County throughout the last decade (table 4) (Utah Govenor's Office of Planning and Budget, unpublished data reported in Utah Division of Water Resources, 1999). Trade replaced agriculture as the third-largest employment provider in the county between 1994 and 1997; agriculture is expected to fall below the service industry in terms of number of people employed by 2020 (table 4) (Utah Governor's Office of Planning and Budget, unpublished data reported in Utah Division of Water Resources, 1999). Although employment in agriculture and the number of farms is decreasing (table 4), agricultural commodity production is expected to remain an important part of Sanpete County's economy. Most farming occurs on the unconsolidated valley-fill deposits that also serve as the principal source of drinking water for the residents of Sanpete Valley. There are 101,760 acres (41,182 hm^2) of irrigated cropland in Sanpete County (plate 4) (Utah Division of Water Resources, 1999); most irrigated cropland is in the central portions of Sanpete and Arapien Valleys. Alfalfa is an important crop in Sanpete County (table 5, plate 5). The eastern and western margins of the valley are mostly rangeland for sheep and cattle. Turkey farms (figures 3 and 4), an important source of economic income to Sanpete County (table 5), are common, particularly on the northwestern arm of upper Sanpete Valley between Moroni and Fountain Green (plate 5).

Climate

Climate in the San Pitch River drainage basin ranges from semiarid in Sanpete Valley to subhumid in the surrounding uplands (Robinson, 1971). Table 6 summarizes climatic data for the three weather stations in the study area that record both temperature and precipitation. The area is characterized by large seasonal and daily temperature variations, especially during the summer (Robinson, 1971). Temperatures reach a normal maximum of 89.4°F (31.9°C) and a normal minimum of 9.8°F (-12.3°C), both recorded at the Moroni station; the normal mean temperature ranges from 71.6°F (22.0°C) at Ephraim in July to 22.7°F (-5.2°C) at Moroni in January (Ashcroft and others, 1992). The average number of frost-free days in Sanpete Valley ranges from 103 at Moroni to 127 at Manti (Ashcroft and others, 1992).

Most of the precipitation in the San Pitch River drainage basin falls as snow in the mountains, particularly the Wasatch Plateau, from November to April (Robinson, 1971). The months of June through August are generally the driest, although brief, intense thunderstorms can locally produce large precipitation totals (Robinson, 1971). Normal annual precipitation in the valley ranges from 9.85 inches (25.02 cm) in Moroni to 13.74 inches (34.89 cm) in Manti (Ashcroft and others, 1992). At elevations above 8,000 feet (2,500 m), the Wasatch Plateau receives an average of 24 inches (60 cm) of precipitation annually (normal climatic information is not available) (Ashcroft and others, 1992).

Normal annual evapotranspiration in Sanpete Valley ranges from 48.54 inches (116.43 cm) in Moroni to 45.62 inches (115.87 cm) in Ephraim (Ashcroft and others, 1992). Robinson (1971) noted that average annual evaporation in the San Pitch River drainage basin is 3.5 times greater than average annual precipitation; table 6 shows the ratio of normal annual evapotranspiration to normal annual precipitation ranges from 4.9 times at Moroni to 3.3 times at Manti, with an average for the three weather stations of 4.0 times.

Table 2. Major tributary streams in the San Pitch River drainage basin (for locations see topographic base on plate 3) (from Robinson, 1971).

Tributary (downstream order)	Type of Stream	Drainage Area (square miles)
Wasatch Plateau		
South San Pitch River Canyon	Intermittent	5.6
Oak Creek near Fairview	Perennial	12.8
Cottonwood Creek	Perennial	8.0
Birch Creek near Fairview	Perennial	10.1
Pleasant Creek	Perennial	18.5
Twin Creek	Perennial	6.9
Cedar Creek	Perennial	6.7
Oak Creek near Spring City	Perennial	9.5
Canal Canyon Creek	Perennial	15.8
Ephraim Canyon Creek	Perennial	22.3
Willow Creek	Perennial	13.1
Manti Canyon Creek	Perennial	31.3
Sixmile Creek	Perennial	34.7
Twelvemile Creek	Perennial	74.8
Total		270
San Pitch Mountains		
Log Hollow Creek	Intermittent	1.2
Birch Creek near Fountain Green	Perennial	2.3
Maple Canyon Creek near Freedom	Intermittent	3.8
Wales Canyon Creek	Perennial	4.5
Peach Canyon Creek	Perennial	5.3
Axhandle Canyon Creek	Perennial	14.5
Dry Canyon Creek	Intermittent	4.7
Maple Canyon Creek near Manti	Intermittent	16.4
Total		53
Cedar Hills		
Big Hollow Creek	Intermittent	20.8

Table 3. Major reservoirs in the San Pitch River drainage basin, Sanpete Valley, Sanpete County, Utah (for locations see topographic base on plate 3) (from Robinson, 1971).

Reservoir (downstream order)	**Major source of supply**	**Capacity** (acre-feet)
Wales Reservoir	Silver Creek	1,480
Chester Ponds	Oak Creek near Spring City	545
Funks (Palisade) Lake	Sixmile Creek and Morrison Coal Mine Tunnel Spring, (D-18-2)35d-Spring	607
Gunnison Reservoir	San Pitch River, Saleratus Creek, and Sixmile Creek	18,210
Ninemile Reservoir	Ninemile Cold Spring, (D-19-2) 9cbb-S1, Peacock Spring, (D-19-2) 4dca-S1, and Sixmile Creek	3,537
Total (rounded)		24,000

Table 4. *Employment distribution and projections for Sanpete Valley, Sanpete County, Utah (modified from Utah Governor's Office of Planning and Budget, unpublished data reported in Utah Division of Water Resources, 1999).*

County Sector	1994	1997	2000	2020
Agriculture	1,033	1,084	1,074	936
Mining	1	10	20	21
Construction	172	235	309	673
Manufacturing	756	911	985	1,378
Transportation, communications, and public utilities	170	212	233	392
Trade	1,012	1,211	1,349	2,238
Finance, insurance, and real estate	154	159	175	270
Services	722	897	1,019	1,835
Government	2,146	2,332	2,576	3,967
Non-farm proprietors	1,202	1,364	1,534	2,615
County Total	7,368	8,415	9,274	14,325

Table 5. *Agricultural statistics for 1980 and 1994 in Sanpete Valley, Sanpete County, Utah (modified from Sanpete County Planning Commission, 1997). Bu. = bushels.*

	1982	1987	1992
Number of Farms	772	761	696
Acreage in Farms	423,918	447,526	447,463
Total Cropland	549	588	643
Pasture and Rangeland Irrigated Land	60899	110744	99061
Market Value of Farm Products	$47,929,000	$62,791,000	$75,914,000
Total Value			
Crops	—	—	—
Livestock and Products	$446,860,000	$59,513,000	$72,175,000
Dairy Products	—	—	—
Number of Animals			
Cattle and Calves	469,000	435,000	388,000
Hogs and Pigs	1,524,000	500,000	1,183,000
Sheep and Lambs	269,000	242,000	206,000
Turkeys	346,674,000	519,425,000	873,464,000
Value of Poultry	$22,996,000	$32,642,000	$42,357,000

1980 Agricultural Crop Statistics

Product	Acres Planted	Acres Harvested	Production	% of State Total
Wheat	17,100	15,600	373,200 bu.	4.17%
Corn (grain)	—	undisclosed	—	—
Corn (silage)	—	1,400	25,200 tons	1.68%
Barley	3,300	3,100	235,400 bu.	2.17%
Alfalfa Hay	—	10,800	50,200 tons	2.72%

1994 Agricultural Crop Statistics

Product	Acres Planted	Acres Harvested	Production	% of State Total
Wheat	6,500	5,800	193,000 bu.	2.75%
Corn (grain)	100	100	8,000 bu.	0.28%
Corn (silage)	700	600	11,400 tons	1.21%
Barley	—	2,400	2,000 n/a	135,000 bu. 1.68%
Alfalfa Hay	—	13,900	54,200 tons	2.46%

Figure 3. *View to the east of a typical turkey farm in Sanpete Valley, Sanpete County, Utah. Wasatch Plateau is in background.*

Figure 4. *Common turkey shed in Sanpete Valley, Sanpete County, Utah.*

Table 6. *Climate data for Sanpete Valley, Sanpete County, Utah (from Ashcroft and others, 1992). Temperature in °F; precipitation and evapotranspiration reported in inches.*

Moroni

County: Sanpete	Latitude: 39° 32' N.	Longitude: 111°35' W.	Elevation: 5560 Feet	Period: 1948-1992*

Element	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Normal maximum temperature	35.6	41.8	50.9	61.0	70.9	81.8	89.4	86.8	78.6	66.0	49.7	37.8	62.5
Normal minimum temperature	9.8	15.5	22.5	28.2	35.5	42.1	49.3	47.8	39.3	30.2	21.6	12.2	29.5
Normal mean temperature	22.7	28.7	36.7	44.6	53.2	62.0	69.3	67.3	58.9	48.1	35.6	25.0	46.0
Normal precipitation	0.85	0.82	0.95	0.70	0.81	0.57	0.67	0.77	1.01	0.91	0.86	0.93	9.85
Evapotranspiration	0.83	1.31	2.57	4.12	6.02	7.48	8.47	7.32	5.08	3.08	1.41	0.84	48.54

Last spring freeze			First fall freeze			Freeze free				
Early	Average	Late	Early	Average	Late	Short	Average	Long	Period	Years
May 5	Jun 4	Jun 30	Aug 12	Sep 19	Oct 4	47	103	133	1948-92	39

* Percentage of period with data: 95% for temperature, 98% for precipitation, 96% for snowfall.

Ephraim Sorensons Field

County: Sanpete	Latitude: 39° 21' N.	Longitude: 111°35' W.	Elevation: 5670 Feet	Period: 1948-1992*

Element	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Normal maximum temperature	34.5	40.4	48.7	58.2	68.9	80.5	88.6	86.0	76.3	64.6	48.4	36.6	61.0
Normal minimum temperature	12.3	18.2	25.2	31.7	39.3	47.2	54.6	52.6	43.9	34.4	24.4	14.9	33.2
Normal mean temperature	23.4	29.3	36.9	44.9	54.1	63.8	71.6	69.3	60.1	49.5	36.4	25.7	47.1
Normal precipitation	0.87	0.93	1.32	1.13	1.05	0.72	0.72	0.78	1.20	1.18	0.98	0.96	11.84
Evapotranspiration	0.79	1.23	2.35	3.72	5.56	7.10	8.06	6.97	4.75	2.94	1.34	0.80	45.62

Last spring freeze			First fall freeze			Freeze free				
Early	Average	Late	Early	Average	Late	Short	Average	Long	Period	Years
Apr 17	May 24	Jun 30	Sept 9	Sept 25	Oct 20	79	123	173	1948-92	41

* Percentage of period with data: 98% for temperature, 97% for precipitation, 64% for snowfall.

Manti

County: Sanpete	Latitude: 39° 15' N.	Longitude: 111°38' W.	Elevation: 5740 Feet	Period: 1928-1992*

Element	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Normal maximum temperature	36.9	42.4	50.6	59.8	69.4	79.8	86.7	84.4	75.6	64.6	49.6	38.3	61.5
Normal minimum temperature	13.9	19.0	25.1	31.9	39.5	47.4	54.7	52.7	44.2	34.6	25.0	16.2	33.7
Normal mean temperature	25.4	30.7	37.9	45.9	54.4	63.6	70.7	68.6	59.9	49.6	37.3	27.2	47.6
Normal precipitation	0.98	1.02	1.53	1.41	1.28	0.81	0.82	0.98	1.40	1.29	1.14	1.06	13.74
Evapotranspiration	0.87	1.31	2.53	3.97	5.71	6.99	7.78	6.76	4.72	2.93	1.39	0.86	45.81

Last spring freeze			First fall freeze			Freeze free				
Early	Average	Late	Early	Average	Late	Short	Average	Long	Period	Years
Apr 7	May 22	Jun 30	Sept 8	Sep 27	Oct 20	79	127	175	1928-92	64

* Percentage of period with data: 99% for temperature, 99% for precipitation, 99% for snowfall.

PREVIOUS INVESTIGATIONS

Regional Investigations

Early regional reconnaissances of the geology of the Sanpete Valley area were made by G.K. Gilbert (1875), E.E. Howell (1875), E.D. Cope (1880), C.E. Dutton (1880), and E.M. Spieker (for example, 1930, 1931, 1934, 1936a, 1936b). Relatively recent mapping includes that of Witkind (1982, 1994), Witkind and others (1987), Witkind and Weiss (1991), Lawton and others (1997), and Weiss and Sprinkel (2000). Figure 5 shows the simplified geologic map for Sanpete Valley. A detailed discussion of the regional geology from previous investigators is included in appendix B.

Modern Ground-Water Studies

Wilberg and Heilweil (1995) produced a ground-water flow model for Sanpete Valley. Horns (1995) studied nitrate contamination in the Moroni area, especially as it applied to siting of a public water-supply well. Snyder and Lowe (1996, 1998) mapped recharge and discharge areas for the principal valley-fill aquifers in Sanpete and Arapien Valleys. Wallace and Lowe (1997) mapped ground-water quality in Sanpete and Arapien Valleys. Lowe and others (1999) evaluated the relationship of ground-water quality to ground-water recharge and discharge areas for several valley-fill aquifers in Utah, including Sanpete and Arapien Valleys.

GEOLOGIC SETTING

General

The San Pitch River drainage basin is in the Basin and Range-Colorado Plateau transition zone (Stokes, 1977), which contains features characteristic of both the Basin and Range and Colorado Plateau physiographic provinces. Spieker (1946) described these features well, as follows.

> The eastern margin of the plateau [Wasatch Plateau] is a sweeping stretch of barren sandstone cliffs, a southward continuation of the Book Cliffs, surmounted by higher tabular masses, in all of which the strata dip at low angles and are essentially parallel, in the general habit of the Colorado Plateaus [sic]. On the western margin the strata plunge to-ward Sanpete and Sevier Valleys in the great Wasatch monocline, at the base of which the structure is complex and a variously deformed rock succession is broken by several angular unconformities; the geologic features here are typical of the Great Basin, and their eastern limit follows in a general way the western border of the plateau.

Stratigraphy

Stratigraphic units exposed in the Sanpete Valley area range from Jurassic to Quaternary in age. Generalized stratigraphy with information on hydrostratigraphic characteristics in the San Pitch River drainage basin is shown in table 7, and the general distribution of rock units is shown in figure 5. Plate 3 provides detailed geologic mapping and stratigraphic unit descriptions for the San Pitch River drainage basin; the sources of mapping for plate 3 are shown on figure 5. The San Pitch Mountains and Wasatch Plateau both consist of Jurassic to Tertiary sedimentary rocks. Tertiary limestone and mudstone cap both ranges. Cretaceous sandstones and conglomerates are steeply tilted on the east side of Sanpete Valley and unconformably underlie Tertiary rocks that are folded as a monocline in the Wasatch Plateau; these Cretaceous and Tertiary rocks form a syncline in the San Pitch Mountains. Beneath the Cretaceous units are the Jurassic Twist Gulch Formation and Arapien Shale; the Arapien Shale contains evaporite deposits. The Cedar Hills consist of the Tertiary volcaniclastic and pyroclastic Moroni Formation, mostly tuff and andesite. Consolidated rocks have a maximum combined thickness of more than 29,000 feet (9,000 m) (table 7). Unconsolidated valley-fill deposits are at least 500 feet (150 m) thick in Sanpete Valley along the western margin (Robinson, 1971; Lawton and others, 1997).

Structure

Sanpete Valley is bounded on the east by the Wasatch monocline, a 50-mile-long (80 km) structure along which strata dip to the west below Sanpete Valley from their near-horizontal dip atop the Wasatch Plateau, and become less steep beneath Sanpete Valley alluvium (Spieker, 1949a). The westward-facing downwarp of the Wasatch monocline is disrupted at many locations by north- and northeast-striking normal faults (plate 3), which in many locations are paired to form long, narrow grabens (Witkind and others, 1987). The strike of the monocline ranges from N. 20° E. to N. 30° E., and flank dips range from 25 to 45 degrees (Spieker, 1949a). The tilted beds on the Wasatch monocline have been cut by westward-flowing consequent streams to form deep, sinuous canyons extending eastward into the Wasatch Plateau (Witkind and others, 1987). Along the base of the monocline is a narrow belt of Tertiary rocks that have been folded into a tilted Z-shaped sequence cut by several syngenetic faults, all likely the result of one or more thrusting events (Spieker, 1949a,b).

The San Pitch Mountains, a north-south-trending, oval-shaped upland composed of sedimentary rocks that have been folded to form a southward-plunging syncline, is completely surrounded by valley lowlands (Witkind and others, 1987). The mountains are imprinted with two synforms that are part of the Gunnison thrust system: (1) a shallow, moderately closed, northward-trending synform in Tertiary strata, and (2) a deeper synform along the eastern front of the plateau having an overturned eastern limb and consisting mostly of Jurassic and Cretaceous strata (Weiss and Sprinkel, 2000). Along the eastern margin of the San Pitch Mountains, the strata are intensely deformed into a gigantic Z-shaped structure (Gilliland, 1952). The southeastern margin of the mountains is characterized by several north-trending grabens (Witkind and others, 1987) which are interspersed in a complex zone of imbricate reverse faults (Weiss and Sprinkel, 2000). To the north, the mountains are less faulted (plate 3), and are characterized by steep cliffs rising high above the adjacent valley floors (Witkind and others, 1987). Lawton (1985) and Lawton and others (1997) map thrust faults along the northeastern base of the San Pitch Mountains, emphasizing their most characteristic feature – the series of synoro-

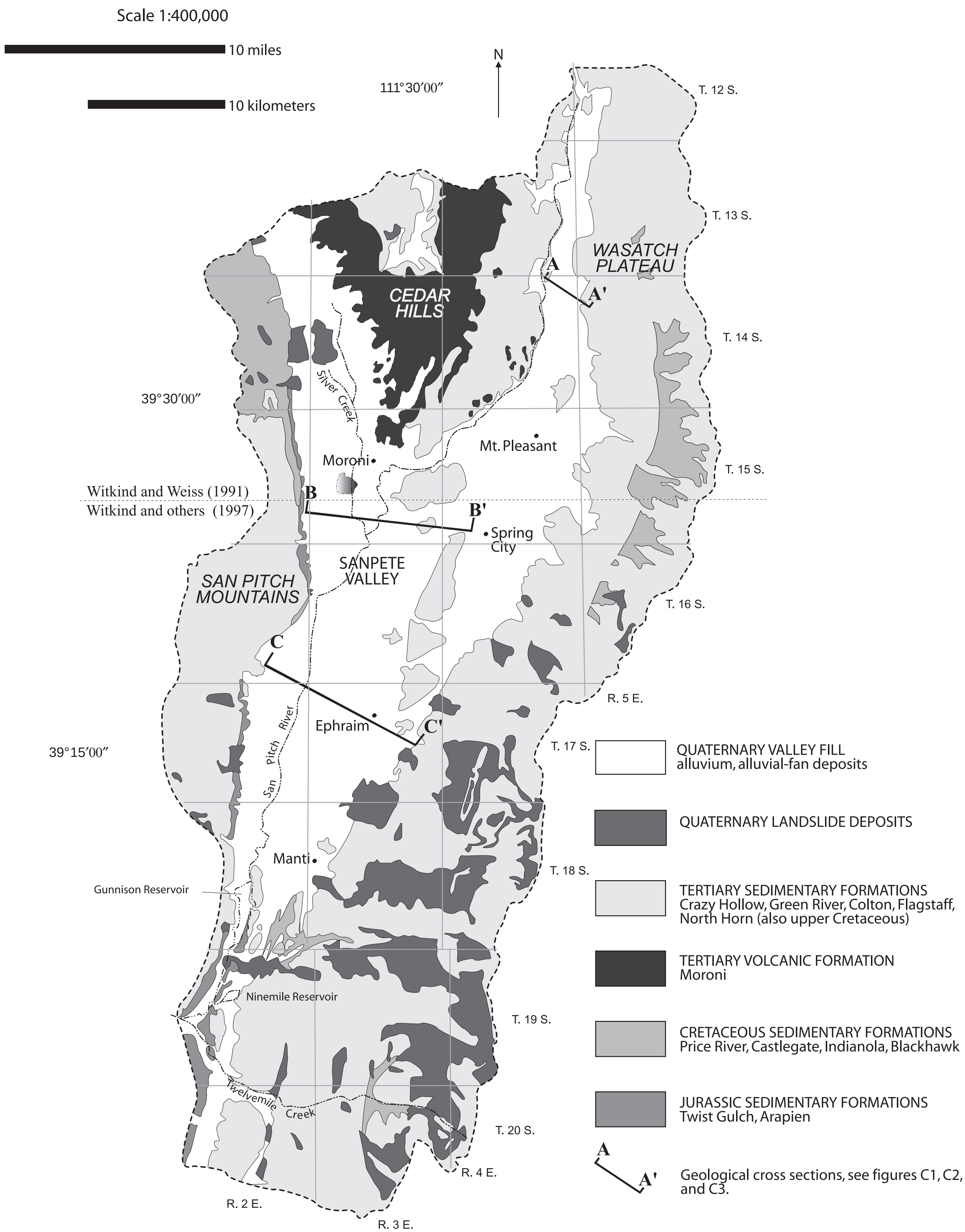


***Figure 5.** Simplified geology and sources of geologic mapping for Sanpete Valley, Sanpete County, Utah. See plate 3A for a more detailed geologic map.*

Table 7 . *Generalized stratigraphy of Sanpete Valley and surrounding area; sources of information and interpretation are from: (1) Spieker (1946), (2) Hardy (1952), (3) Robinson (1971), (4) Sprinkel (1982), (5) Lawton (1985), (6) Witkind and others (1987), (7) Banks (1991), (8) Witkind and Weiss (1991), (9) Lawton and others (1993), (10) Weiss (1994), (11) Sprinkel (1994), (12) Fong (1995), (13) Lawton and others (1997), (14) Sprinkel and others (1999), (15) Lawton and Weiss (1999), and (16) Schwans and Campion (1997).*

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics[10]
Quaternary	Surficial deposits[1,3,8,10,6]		Clay, silt, sand, and gravel Valley fill: 0-500+ feet Other sedimentary surficial deposits located in the surrounding mountainous area, combined: 0-1,450 feet.	Valley fill- poorly to moderately consolidated and unconsolidated alluvial-fan, floodplain, and channel deposits (debris-flow origin); pediment-mantle deposits; colluvial and mass wasting deposits (slide and slump); lacustrine deposits; tufa deposits; stream deposits; and minor glacial deposits.	Principal aquifer of Sanpete Valley. Has low to high permeability and yields small to large quantities of ground water; landslide, terrace, stream, and glacial deposits not significant sources of water.
Tertiary	Moroni Formation[3,7,8]		Volcaniclastic and pyroclastic rocks including ash-flow tuffs, welded tuffs, conglomerate, and tuffaceous sandstone; tuff is gray, brown, red, and green; conglomerate contains limestone, quartzite, and volcanic clasts; 0-2,000 feet.	The Moroni Formation unconformably overlies Jurassic to early Tertiary strata and is primarily exposed in the Cedar Hills and the northeastern and northwestern hills of Sanpete Valley; volcanic flows and some fluvial conglomerate.	Low permeability in general; locally yields water to springs in Cedar Hills.
	Crazy Hollow Formation[1,10]		Red and reddish-brown sandstone and shaly siltstone with minor conglomerate and limestone; 0-1,000 feet.	Fluvial and lacustrine rocks deposited near or along the southwest arm of Lake Uinta that correspond to the Uinta Formation in the Uinta Basin; the Crazy Hollow Formation interfingers with the underlying Green River Formation.	Low permeability in general; locally high yields where fractured.
	Green River Formation[1,10]	Limestone member	Gray and brown muddy, micritic limestone, calcareous mudstone, and shale; the uppermost limestone beds are yellowish-brown, silicified, and contain stromatolites and minor interbeds of tuff.	Deposited in a fresh-water lacustrine environment.	Low permeability in shale; moderate permeability in sandstone and where fractured.
		Shale member	Green and gray calcareous mudstone and shale with minor siltstone, sandstone, and limestone; combined thickness of two members: 0-1,000 feet.		

Table 7. *(continued)*

System	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics[10]
Tertiary	Colton Formation[3]	Variegated red, pink, green, olive, and brown mudstone, sandstone, and siltstone with minor limestone and calcareous mudstone; 325-850 feet.	Deposited in both fluvial and lacustrine environments; the contacts between the Colton Formation and the underlying Flagstaff Formation and the overlying Green River Formation are gradational.	Water-bearing properties unknown; not a significant source of water.
	Flagstaff Limestone[2,3]	Gray and yellow limestone with some dolomite, mudstone, and green shale; some intervals contain algal nodules and oncolites; 0-1,000 feet.	Deposited in a lacustrine environment; the North Horn Formation regionally grades upward into the lower Tertiary Flagstaff Limestone.	Low permeability in general; locally yields water from fractures.
	North Horn Formation[2,9,13]	Red and brown mudstone, sandstone, conglomeratic sandstone, conglomerate, and minor limestone and coal; 500-3,000 feet.	Deposited in both fluvial and lacustrine environments; unconformably overlies the Indianola Group in the study area.	Variable permeability due to hetereogenous nature; moderate to high permeability in primary framework and secondary fractures.
Cretaceous	Price River Formation[8, 13]	Gray conglomeratic sandstone, conglomerate, and sandstone with minor shale; 0-1,200 feet.	Deposited in a fluvial environment; unconformably overlies the Blackhawk Formation in the eastern part of the study area; equivalent to the lower North Horn Formation in the western part of the study area (Lawton and others, 1993).	Moderate to high permeability, especially where fractured.
	Castlegate Sandstone[8]	Brownish-gray sandstone with minor shaly siltstone, carbonaceous shale, and conglomerate; 50-500 feet.	Unit has limited exposure in the study area, and where present, conformably overlies the Blackhawk Formation in the Wasatch Plateau; deposited in a fluvial environment.	Not a significant source of ground water.
	Blackhawk Formation[6]	Gray and brown sandstone, shaly siltstone, shale, carbonaceous shale, and coal; 700-1,000 feet.	Unit has limited exposures in the eastern part of the study area, mostly in drainages of the Wasatch Plateau; typically in fault contact with the Cretaceous-Tertiary North Horn Formation; deposited in both continental and deltaic environments.	Not a significant source of ground water.

Table 7. (continued)

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics[10]
Cretaceous	Indianola Group[7,13,14,15,16]	Sixmile Canyon Formation	Clast-supported conglomerate and conglomeratic sandstone with intervals of red-weathering sandy siltstone, conglomerate, conglomeratic sandstone, sandstone, carbonaceous shale, and coal; 100-15,000 feet for entire group thickness.	Indianola Group is a lithologically diverse group of clastic sediments deposited in both marine and nonmarine environments.	Moderate to high permeability in sandstone units and along bedding planes and fractures; yields large quantities of water to some springs.
		Funk Valley Formation	Conglomerate, pebbly sandstone, sandstone, red siltstone, and gray shale.	Deposited in fluvial, shoreline, and open-marine environments.	
		Allen Valley Shale	Fossiliferous dark-gray to black shale with thin siltstone, very fine-grained sandstone, and some gray limestone.	Deposited in a marine environment.	
		Sanpete Formation	Cross-bedded sandstone and pebbly sandstone with gray siltstone and sandy siltstone.	Marine and marginal-marine shale and sandstone.	
		San Pitch Formation	Reddish-brown to gray conglomerate; boulder to cobble conglomerate with interbedded red silty mudstone and sandstone.	Deposited in a fluvial environment.	
	Cedar Mountain Formation[8,10,14]		Variegated red, orange, gray, and green mudstone, siltstone, and limy sandstone with minor lenses of sandstone, pebbly sandstone, and pebble conglomerate; some mudstone intervals contain oncolites and lime nodules; 60-1,400 feet.	Deposited in a fluvial environment; contains multiple intraformational unconformities; exposures in the study area are limited to Salina Canyon and along the edges of the San Pitch Mountains.	Not a significant source of ground water.
Jurassic	Twist Gulch Formation[2,8]		Reddish-brown sandstone with siltstone and silty mudstone and lenticular conglomeratic sandstone; 3,000 feet.	Deposited in a marine to marginal-marine environment.	Aquitard; extremely low permeability.
	Arapien Shale[2,4,6,11]		Gray to green-gray mudstone with interbedded siltstone, limestone, gypsum, and some salt; 0-7,000 feet.	Deposited in a marine environment; tight folds and thrusts are common likely due to the thin-bedded nature and incompetent lithologies.	Aquitard; extremely low permeability; gypsum and salt beds are source of high total-dissolved solids and sulfate and chloride ions.

genic, predominantly clastic deposits which record the foreland-breaking sequence of thrust deformation largely responsible for most structures in central Utah.

The Sanpete-Sevier anticline, a 65- to 70-mile- (105-113 km) long, sinuous antiform with structural relief of up to 20,000 feet (6,100 m), underlies the Sanpete Valley alluvial fill (Gilliland, 1963); it is interpreted to be a large fault-propagation fold (Weiss and Sprinkel, 2000). The Sanpete Valley block has been down-dropped along its eastern margin by the Gunnison fault zone (Weiss, 1982; Hecker, 1993), which may have been active within the last 370 years (Fong, 1991). The structural relief on the Gunnison fault zone is greatest along the northern end of the San Pitch Mountains, and as much as 4,400 feet (1,350 m) near Wales; the magnitude of displacement on the Gunnison fault zone decreases to zero at the south end of the mountains (Lawton, 1985; Weiss and Sprinkel, 2000). Local diapirism has modified structures in several places in Sanpete Valley (Weiss and Sprinkel, 2000), especially in the south where the Arapien Shale is exposed along the western valley margins.

GROUND-WATER CONDITIONS

Background

Below, we summarize ground-water conditions and ground-water quality; here we emphasize hydrogeologic setting and water quality as subsequently we evaluate the relationship between these characteristics and nitrate to determine potential correlations. A comprehensive description of ground-water conditions and ground-water quality is in appendix C.

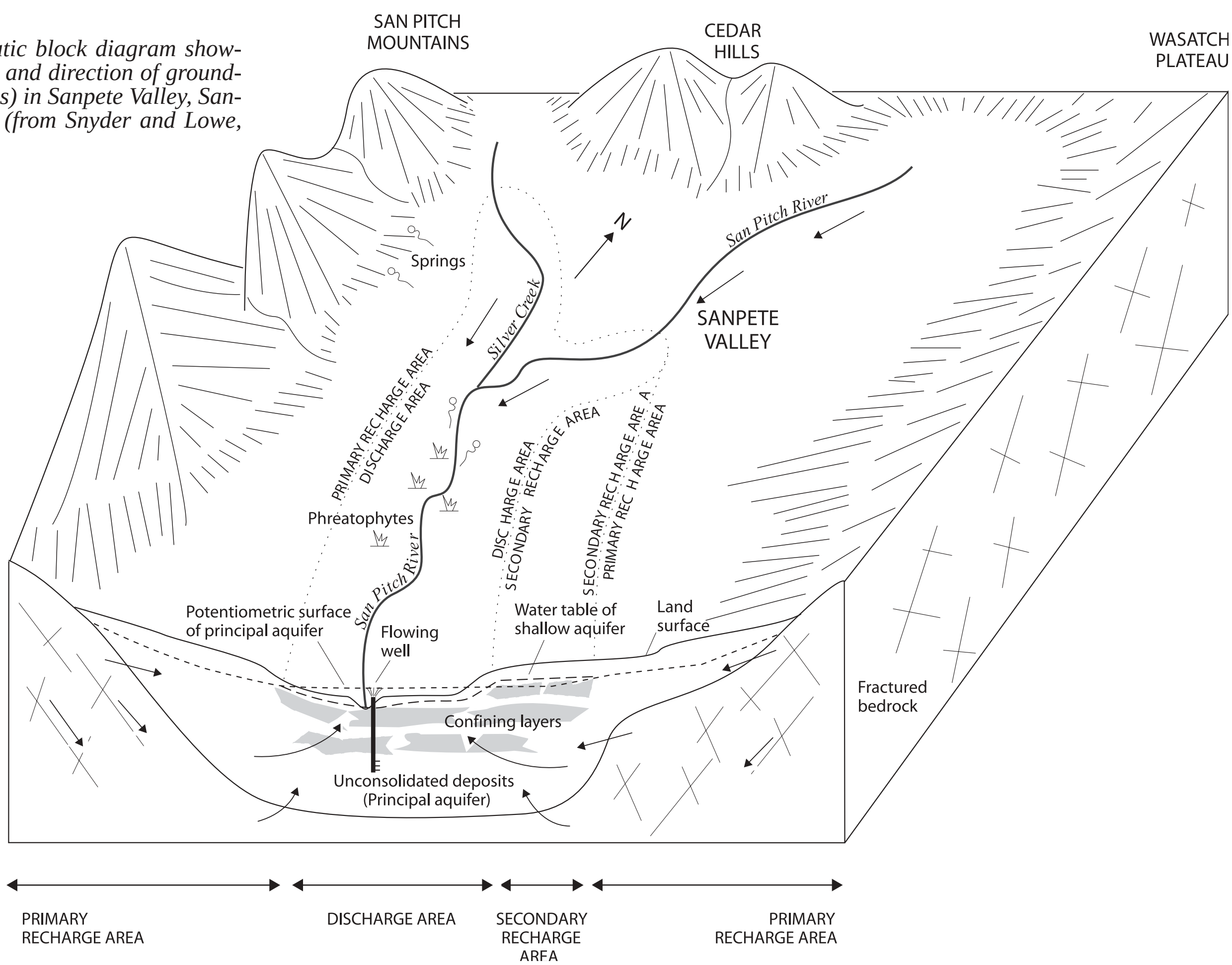
Ground-Water Conditions

Ground water in the Sanpete Valley area is obtained principally from unconsolidated deposits of the valley-fill aquifer (Wilberg and Heilweil, 1995). Ground water in the valley-fill aquifer of Sanpete Valley occurs under confined and unconfined conditions in unconsolidated deposits (figure 6) (Robinson, 1971). In areas where the principal valley-fill aquifer is under confined conditions, it is generally overlain by a shallow unconfined aquifer (figure 6).

The valley fill consists primarily of interfingered layers of clay, silt, sand, and gravel. Sediments are generally coarser grained in alluvial fans along the mountain fronts and finer grained in the central portions of the valley.

Areas where confining layers are thicker than 20 feet (6 m) having an upward ground-water gradient are called discharge areas, and contain artesian wells (Anderson and others, 1994). The discharge area follows the lowlands along the San Pitch River from west of Mount Pleasant to Gunnison Reservoir, and along the northwestern arm along Silver Creek (figure 6) (Snyder and Lowe, 1998). Secondary recharge areas are where confining layers are thicker than 20

Figure 6. Schematic block diagram showing recharge areas and direction of ground-water flow (arrrows) in Sanpete Valley, Sanpete County, Utah (from Snyder and Lowe, 1998).



feet (6 m) and the ground-water gradient is downward (Anderson and others, 1994). Fine-grained sediments in alluvial-fan deposits form a band of secondary recharge areas along the eastern edge of southern Sanpete Valley; along the northern San Pitch Mountains, alluvial-fan deposits are coarser than those on the eastern side of the valley, and secondary recharge areas are present only near the distal ends of alluvial fans (figure 6) (Snyder and Lowe, 1998).

Primary recharge areas have no confining layers and a downward component of ground-water flow and typically follow the valley margins, especially on alluvial fans (figure 6). Unconfined conditions exist in the northeastern arm of Sanpete Valley, north of Fairview, where coarse-grained material predominates, and along the base of the Wasatch Plateau on the eastern side of Sanpete Valley. The valley-fill aquifer is unconfined only in a narrow band along the western side of Sanpete Valley. Unconfined conditions exist in Arapien Valley (Robinson, 1971). Because of the lack of thick (20 feet [6 m]), protective clay layers, these primary recharge areas are vulnerable to surface sources of ground-water contamination (Lowe and Snyder, 1996).

The potentiometric surface (figure 7) of ground water in the valley-fill aquifer is irregular and depends on the well depth, season, and the year water-level measurements are made (Robinson, 1971). In unconfined parts of the aquifer, the potentiometric surface corresponds to the water table; in

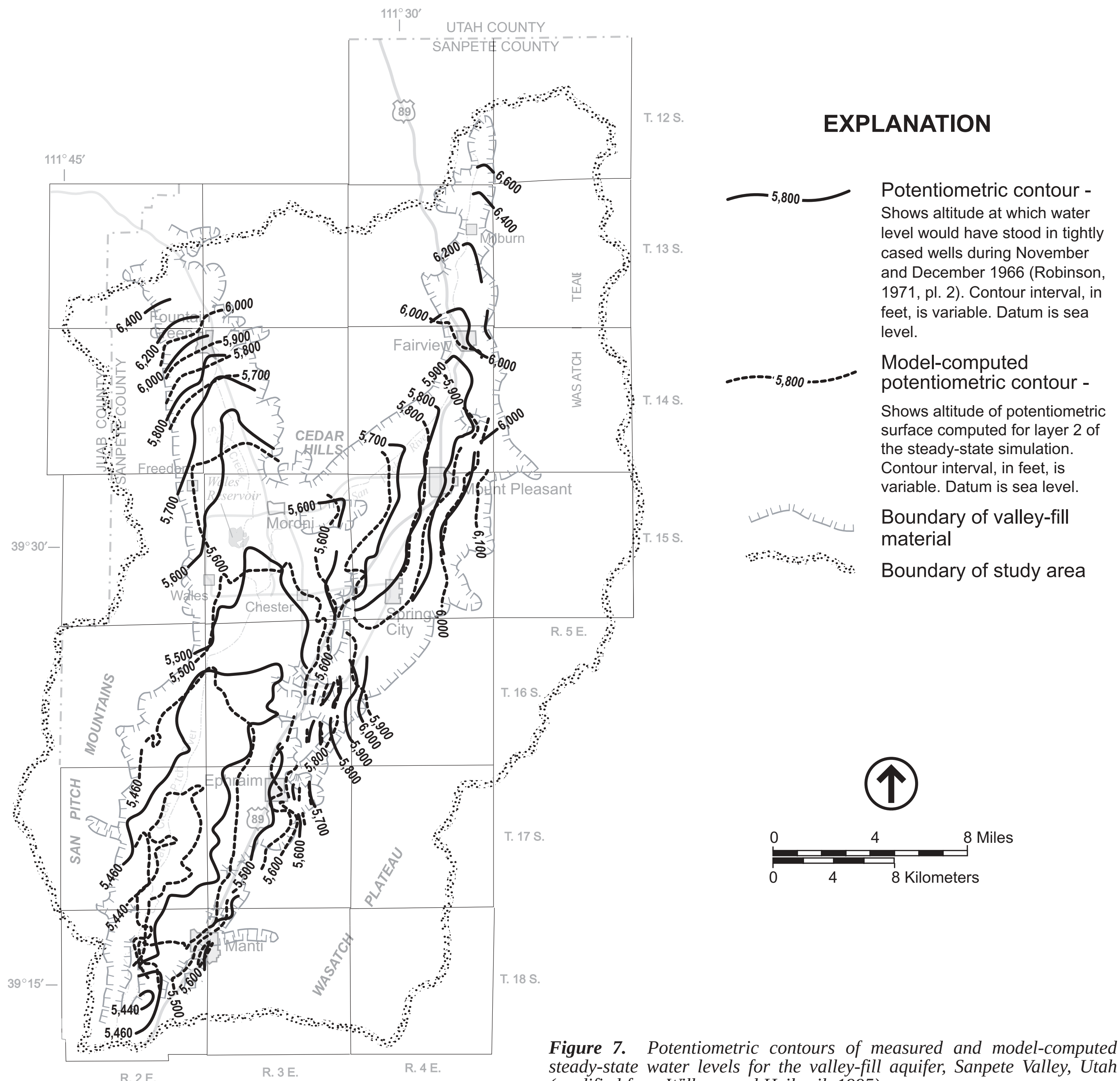


Figure 7. Potentiometric contours of measured and model-computed steady-state water levels for the valley-fill aquifer, Sanpete Valley, Utah (modified from Wilberg and Heilweil, 1995).

the confined parts of the aquifer, the potentiometric surface represents the hydrostatic pressure, or head, a parameter controlling the elevation to which water will rise in wells. The potentiometric surface generally conforms to the contour of the valley floor.

Ground-water flow is generally from the higher elevation recharge areas to lower elevation discharge areas. Ground water generally flows westward from the Wasatch Plateau and eastward from the San Pitch Mountains toward the San Pitch River and Silver Creek, and then southward toward Gunnison Reservoir.

Ground-Water Quality

Ground-water quality in Sanpete Valley is generally good and suitable for most uses; table 8 summarizes ground-water quality classes based on total-dissolved-solids concentrations, and the relationship of total-dissolved-solids concentrations to specific conductance in Sanpete Valley. Ground water in the valley-fill aquifer is generally a mixed type containing calcium, sodium, magnesium, and bicarbonate ions; however, water from many wells, especially shallow ones on the west side of the valley, is a mixed type containing magnesium, sodium, sulfate, and chloride ions (Wilberg and Heilweil, 1995).

Nitrate, typically associated with human activities, has been identified in ground water in Sanpete Valley in previous studies and in this report. The Utah ground-water quality (health) standard for nitrate as nitrogen is 10 mg/L. Nitrate concentration exceeding this standard was identified in a Moroni public-supply well in the 1990s; the well was replaced and taken off line. This study was prompted in part because of this incidence coupled with the potential nitrate contamination associated with pervasive turkey and cattle farm operations in the valley and is discussed in detail in subsequent sections.

SOURCES OF GROUND-WATER QUALITY DEGRADATION

Background

Below, we summarize potential sources of ground-water quality degradation; a more detailed discussion is described in appendix D. Degradation in ground-water quality may be due to either natural sources or contamination associated with human activities. Many constituents dissolved in water are derived from geologic materials such as rock or sediment. Some sources of water-quality degradation include: dissolved solids, nitrate (atmospheric, biologic, and geologic), agricultural activities (irrigation, pesticide and fertilizer application, raising of nitrogen-fixing crops, livestock grazing, and feed-lot operations), and septic-tank systems (pathogens, household and industrial chemicals, phosphate, and nitrate).

WATER-QUALITY

Results

Ground-water quality in Sanpete Valley is generally very good with total-dissolved-solids concentrations primarily below 1,000 mg/L, although elevated total-dissolved-solids and nitrate concentrations exist locally in the valley-fill aquifer. A trilinear Piper diagram showing general chemistry for 118 wells indicates that ground-water chemistry is mostly calcium-magnesium bicarbonate type, except for two wells having elevated sulfate concentrations (figure 8). Plate 6 summarizes the general chemistry, nutrients, metals, and pesticides data. We determined statistical correlations between some of the data in plate 6 and various land-use parameters, and provide the correlation coefficient for each set of graphs. A correlation coefficient ranges between 1 and -1, and is used for analyzing the relationship between selected data sets. A value near 1 or -1 indicates a predictable relationship between data sets, whereas a value approaching zero reflects a non-predictable relationship between selected parameters. Most of our results correspond to non-predictable relationships as discussed below.

Total-Dissolved-Solids Concentrations

Measured total-dissolved-solids concentrations range from 234 to 2,752 mg/L (plate 6); the average measured total-dissolved-solids concentration from the valley-fill aquifer is 531 mg/L. Measured total-dissolved-solids concentrations for ground-water samples from 66 percent of the wells tested for general chemistry are below 500 mg/L.

Table 8. *Water-quality classification in Sanpete Valley, Sanpete County, Utah (modified from Robinson, 1971).*

CLASS	CONCENTRATION OF DISSOLVED SOLIDS (mg/L)	SPECIFIC CONDUCTANCE (Micromhos per cm at 25°C)	CLASSIFICATION ACCORDING TO THE UTAH WATER QUALITY BOARD
Fresh	less than 500	less than 750	Pristine
	500 - 1,000	750 - 1,400	Drinking Water Quality
Slightly saline	1,000 - 3,000	1,400 - 4,000	
Moderately saline	3,000 - 10,000	4,000 - 14,000	Limited Use
Very saline	10,000 - 35,000	14,000 - 50,000	Saline
Briny	more than 35,000	more than 50,000	

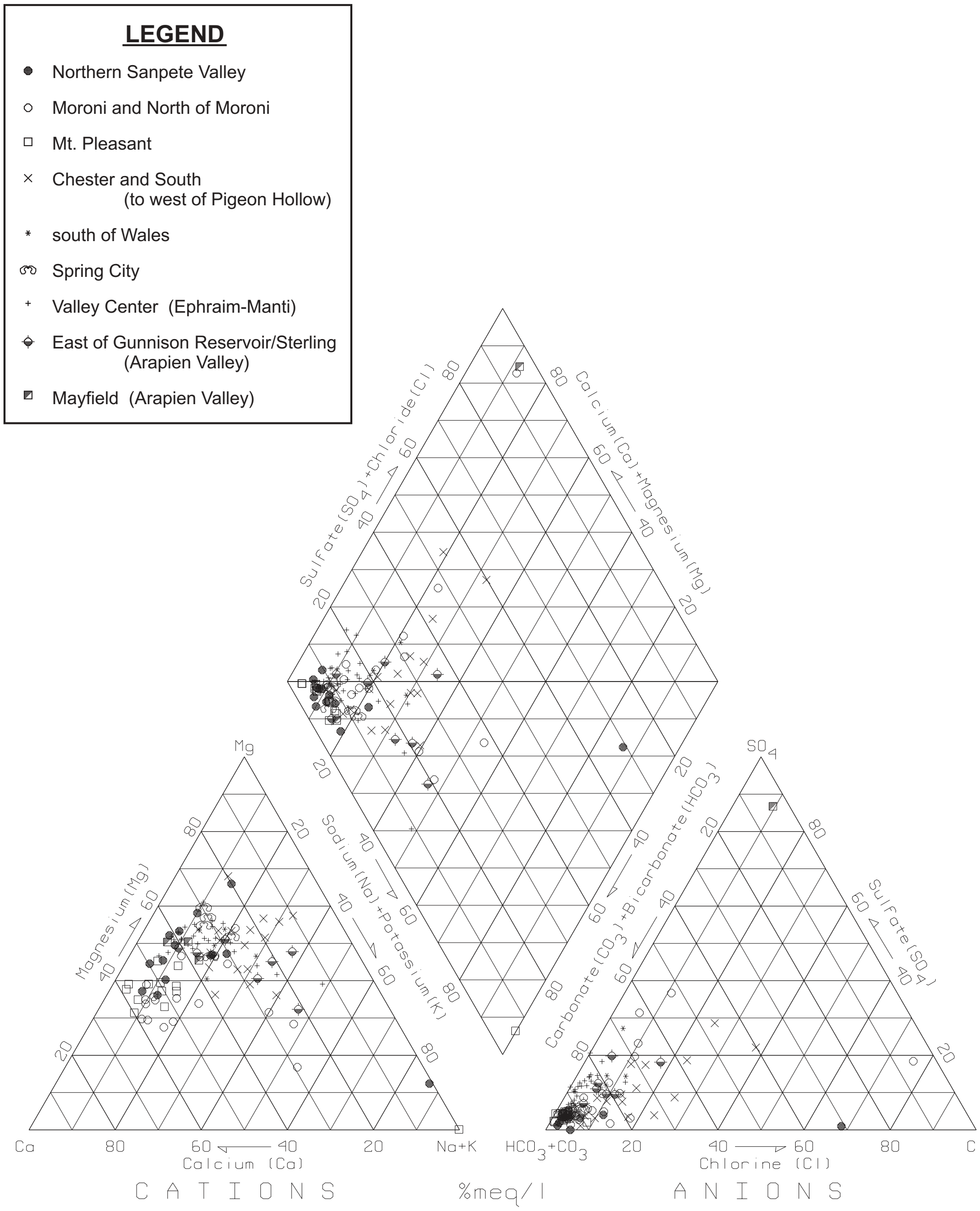


Figure 8. *Piper plot showing overall ground-water chemistry from water wells sampled in this study; the water is dominantly calcium-magnesium-bicarbonate type for Sanpete Valley, Sanpete County, Utah. Different symbols correspond to different areas throughout the valley.*

Total-dissolved-solids concentrations were also calculated from specific-conductance data based on the relation of specific conductance to total dissolved solids from wells for which both types of data were measured (figure 9). The highest quality water, in terms of low measured and/or calculated total-dissolved-solids concentrations, exists in the northeast arm and eastern margin of San Pitch River from Chester to Manti (plate 7). Ground water having measured and/or calculated total-dissolved-solids concentrations generally less than 500 mg/L exists in the northern part of the northwest arm; values range from 266 to 1,304 mg/L. In the central part of the valley, along the western margin of Sanpete Valley from Fountain Green to Mayfield, measured and/or calculated total-dissolved-solids concentrations are generally between 500 and 999 mg/L, but values range from 216 to 2,750 mg/L (plate 7). Similar concentrations exist along the east side of the valley just north of Manti (plate 7). Water having measured and/or calculated total-dissolved-solids concentrations greater than 1,000 mg/L is found in the Moroni area at the south end of the Cedar Hills, along the west side of the bedrock hills south and south-southeast of Chester, and along the east side of the West Hills south of Mayfield (plate 7).

Plate 8 shows the distribution of measured total-dissolved-solids concentrations with respect to perforated-interval-depth category and hydrogeologic setting (recharge/discharge area category). Of the 118 wells sampled and analyzed for general chemistry, 44 are shallow wells (less than 100 feet [30 m] deep), 53 are medium-depth wells (100 to less than 200 feet [30-<61 m] deep), and 21 are deep wells

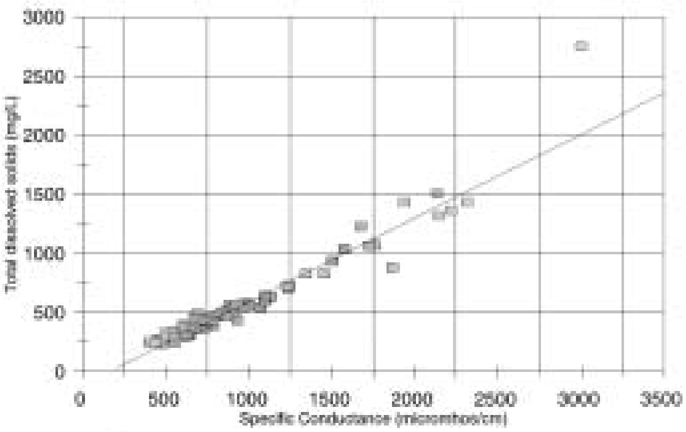


Figure 9. *Relation of specific conductance to total-dissolved-solids concentrations in ground-water samples collected in Sanpete Valley, Sanpete County, Utah. Correlation coefficient is 0.97.*

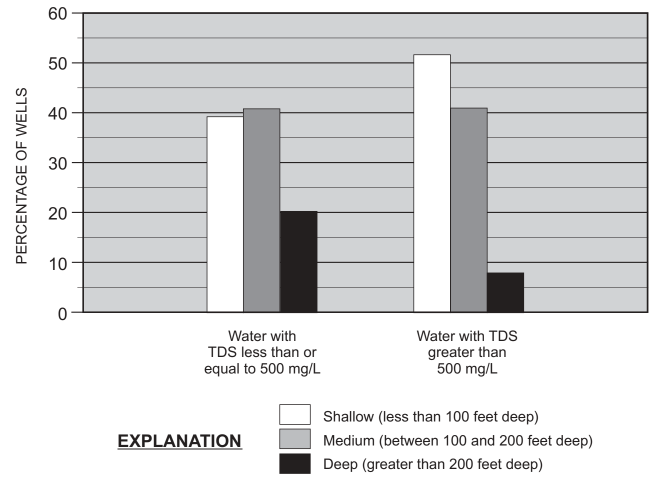


Figure 10. *Percentage of wells in shallow-, medium-, and deep-perforated intervals above and below 500 mg/L total-dissolved-solids (TDS) concentrations in Sanpete Valley, Sanpete County, Utah. Note shallow wells generally have higher TDS.*

(200 feet [61 m] deep or greater) (plate 6). Measured total-dissolved-solids concentrations range from 234 to 2,490 mg/L and average 602 mg/L in shallow wells, range from 244 to 1,068 mg/L and average 468 mg/L in medium-depth wells, and range from 260 to 2,752 mg/L and average 541 mg/L in deep wells (plate 6). Figure 10 summarizes the percentage of wells in each perforated-depth interval that are above or below 500 mg/L measured total-dissolved-solids concentration; shallow wells more commonly have total-dissolved-solids concentrations greater than 500 mg/L compared to deeper wells. Figure 11 indicates no correlation exists between measured total-dissolved-solids concentration and well depth (R- squared is 0.014).

With respect to hydrogeologic setting (plate 8), of the 118 wells sampled and analyzed for general chemistry, 49 are in primary recharge areas, 16 are in secondary recharge areas, and 53 are in discharge areas based on Snyder and Lowe's (1998) mapping. Measured total-dissolved-solids concentrations for primary-recharge-area wells range from 234 to 2,572 mg/L and average 505 mg/L. Measured total-dissolved-solids concentrations for secondary-recharge-area wells range from 344 to 1,322 mg/L and average 646 mg/L. Measured total-dissolved-solids concentrations for discharge-area wells range from 246 to 2,490 mg/L and average 524 mg/L. Figure 12 summarizes the percentage of wells in each hydrogeologic setting category that are above or below 500 mg/L for measured total-dissolved-solids concentration; hydrogeologic setting does not seem to influence ground-water quality.

As mentioned earlier in the report, previous investigators have attributed elevated total-dissolved-solids concentrations to the Jurassic Arapien Shale and the Tertiary Green River and Crazy Hollow Formations. Comparison of plate 3 and plate 7 supports this conclusion. Figure 13 shows the relationship between measured total-dissolved-solids concentrations for some wells and proximity to outcrops of the Arapien Shale, the Green River Formation, and the Crazy Hollow Formation.

A positive correlation between high total-dissolved-solids concentrations in shallow wells and irrigated lands has been noted by previous investigators as mentioned above. Of the 52 shallow wells sampled and analyzed for general chemistry during this study, 28 are within the boundaries of

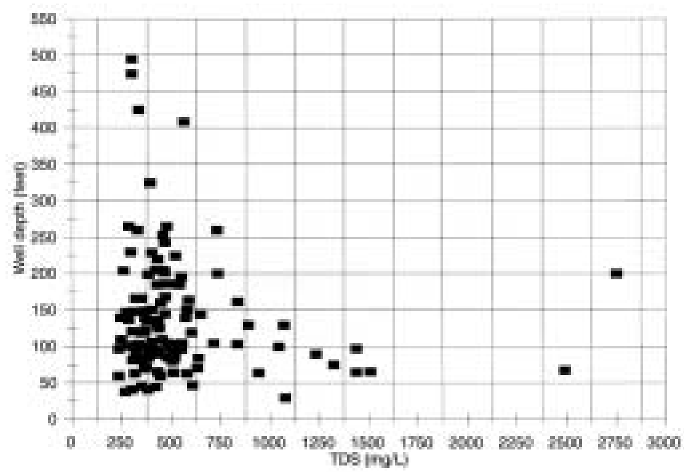


Figure 11. *Relationship between well depth and total-dissolved-solids (TDS) concentrations in Sanpete Valley, Sanpete County, Utah. Correlation coefficient is -0.12 (R-squared is 0.014).*

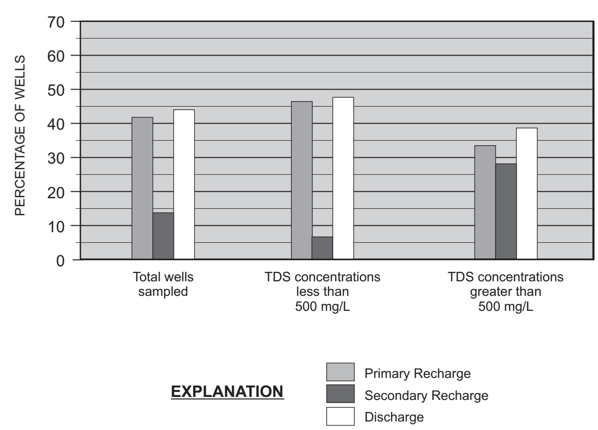


Figure 12 *Percentage of wells in hydrogeologic setting sampled for total-dissolved-solids (TDS) concentrations in primary and secondary recharge and discharge areas that are less than 500 mg/L and greater than 500 mg/L in Sanpete Valley, Sanpete County, Utah. This shows higher TDS concentrations are present in all hydrogeologic settings and that location in hydrogeologic setting does not seem to affect TDS concentrations.*

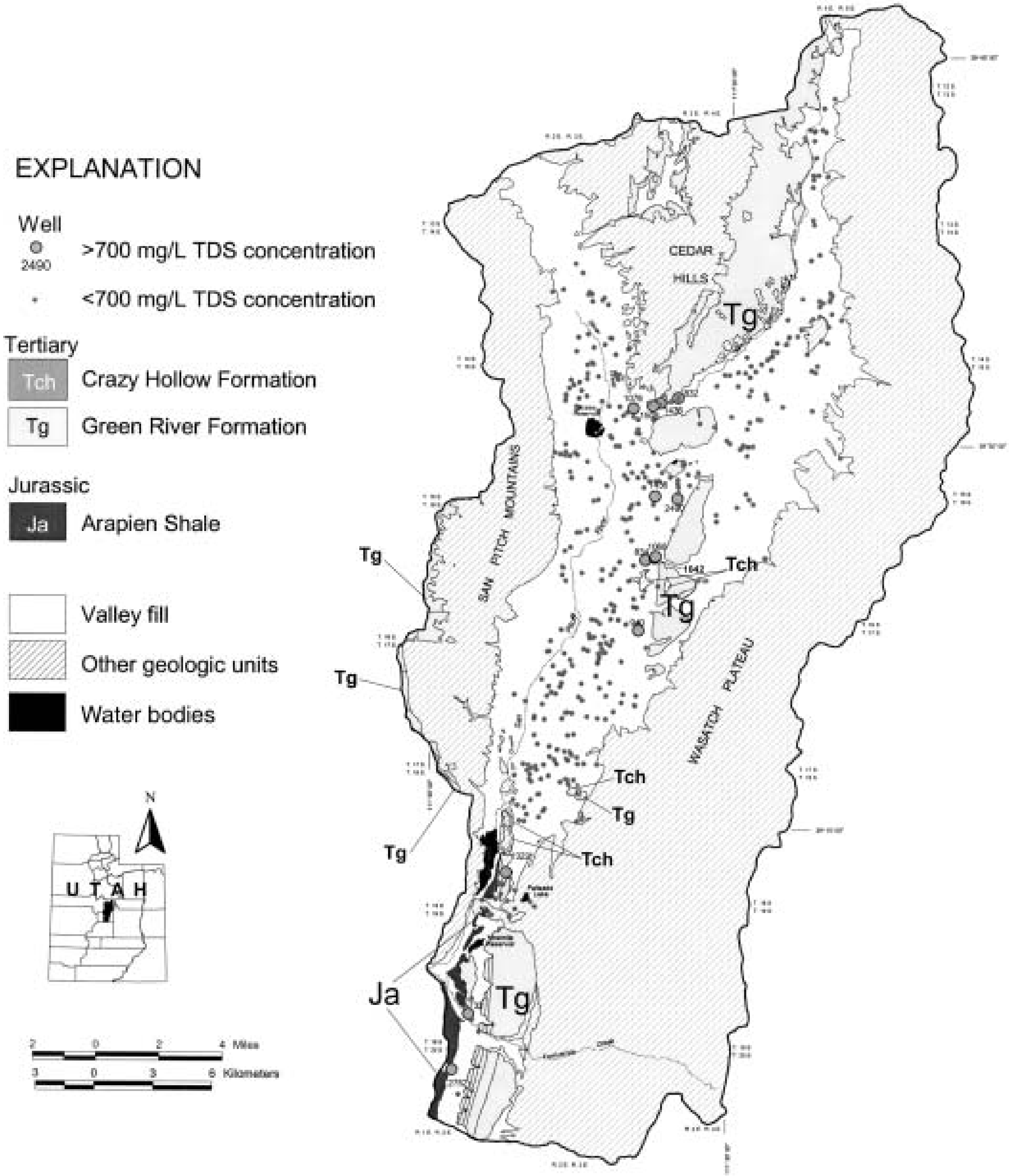


__Figure 13.__ Distribution of elevated total-dissolved-solids-concentration wells and adjacent rock types (Jurassic Arapien Shale and Tertiary Green River and Crazy Hollow Formations) in Sanpete Valley, Sanpete County, Utah.

irrigated lands (plate 4). The average total-dissolved-solids concentration for all wells sampled for general chemistry is 531 mg/L; the average total-dissolved-solids concentration for shallow wells located on irrigated lands is 626 mg/L.

Nitrate

Nitrate values range from less than 0.02 mg/L to 40.2 mg/L (plate 6). Average nitrate concentration in the valley-fill aquifer is about 3.3 mg/L, and 86.5 percent of the ground water from wells analyzed for nitrate yielded values less than 5 mg/L. Sixteen samples (3.5 percent) of the ground water from water wells analyzed in the initial sampling for this study exceeded the Utah drinking-water standard of 10 mg/L. All but one of these high-nitrate wells were resampled–four subsequently yielded nitrate concentrations below drinking-water standards (plate 6; table 9). Two other wells that had initial nitrate concentrations just below 10 mg/L in the initial sampling phase subsequently yielded concentrations exceeding the drinking-water standard when resampled (plate 6; bottom two entries on table 9). Two of the wells that were sampled multiple times are questionable in terms of well identity due to changes in personnel (multiple samplers), but were obtained at least in the same vicinity of the initial high-nitrate-concentration well(s) (table 9). Overall, nitrate concentrations in the valley-fill aquifer are low. Higher nitrate concentrations (> 10 mg/L) exist: (1) along the west side of the Cedar Hills between Fountain Green and Moroni, (2) along the east side of the San Pitch Mountains west-northwest of Moroni, (3) at the south end of the Cedar Hills in the vicinity of Moroni, (4) on the east side of the Round Hills northeast of Mount Pleasant, (5) at several locations along the western margins of the bedrock hills south and south-southeast of Chester, (6) along the east side of the hills bounding the east side of Gunnison Reservoir, and (7) on the east side of the West Hills northeast of Mayfield (plate 1).

Plates 9, 10, and 11 show the distribution of nitrate concentrations with respect to perforated-interval-depth category and hydrogeologic setting. Of the 443 wells sampled and analyzed for nitrate, 147 are shallow wells (less than 100 feet [30 m] deep), 218 are medium-depth wells (100 to 200 feet

Table 9. *Possible sources of nitrate in ground water obtained from wells over more than one sampling interval in Sanpete Valley, Sanpete County, Utah.*

Well location	**Nitrate as N* (mg/L)**	**Depth (ft)**	**Possible source of nitrate**
(D-14-3)17dcd-1	20.7, 19	140	subsidence (well construction); sheep grazing upgradient
(D-14-3)20ada-1	17, 15, 5.99	140	turkey farm, manure near well
(D-14-3-)20aba-1	18, 18, 18.2	105	horse/corral adjacent to well (in subsequent years, corral was moved); turkey farm and sheep grazing upgradient
(D-14-3)28cbc-3*	16.4?, 4.5, 2.04	90.5	turkey manure pile originally stacked adjacent to the well, later was removed
(D-15-3)6cab-1*	17.8, 0.32, 0.4	38	flowing well into a tub; near a turkey farm
(D-15-3)6dbd-1	21.65	53	near a turkey farm (downgradient), flowing well, pond surrounding well may be contaminated by animal waste or used as drinking-water source (for cows)
(D-15-3)10ccb-1	26.9, 29, 19.7	30	chicken coop and chicken roost near well, later removed
(D-15-3)10dad-1	10.7, 9.1, 14.9, 17.5	70	turkey farm
(D-14-4)25dcc-1	21.6, 14.5, 12.2	145	sheep grazing upgradient; possible septic-tank system
(D-16-3)15add-1	15.15, 10.9, 9.14	100	turkey farm
(D-15-3)35dda-1	20.0, 15.4, 5.94	68	septic tank?; downgradient from former animal grazing?
(D-16-3)28bcc-1	12.75, 12.16	142	discharge area pond/animal drinking-water source or animal (cow) waste
(D-13-3)32aad-1	11.44	140	abandoned property; shacks; older septic tank?
(D-18-2)27bdc-1	40.2, 45.3, 33.4	75	dairy farm
(D-18-2)34abd-1	22.42, 0.09	160	unstable well conditions?
(D-19-2)29bdc-1	11.86, 0.36	200	septic tank or manure spread on adjacent farmland
(D-15-3)35dad-1	7.22,? 35.4	No log	turkey sheds nearby
(D-16-3)34cbd-1	9.71, 10.4	64	downgradient from a turkey farm

* see plate 6 for date sample was collected and other ground-water quality information

[30-61 m] deep), and 71 are deep wells (greater than 200 feet [61 m] deep). Perforated-interval depth is not known for four of the sampled wells. Nitrate concentrations for shallow wells range from less than 0.02 to 40.2 mg/L (plate 9) and average 3.5 mg/L. Nitrate concentrations for medium-depth wells range from less than 0.02 to 21.6 mg/L (plate 10) and average 2.4 mg/L. Nitrate concentrations for deep wells range from less than 0.02 to 11.9 mg/L (plate 11) and average 1.7 mg/L. The nitrate concentrations for wells for which perforated-interval depth is not known range from 0.3 to 5.7 mg/L and average of 2.5 mg/L. Figure 14 summarizes the percentage of wells in each perforated-interval depth that are less than 3 mg/L nitrate concentration, between 3 and less than 10 mg/L nitrate, and greater than 10 mg/L. Figure 15 shows the relationship between nitrate concentration and well depth for our data set; the correlation coefficient is -0.16, indicating no correlation. Most of the high-nitrate wells are less than 150 feet [46 m] deep, and in general, average nitrate concentrations decrease with increasing depth.

With respect to hydrogeologic setting (plates 9, 10, and 11), of the 443 wells sampled and analyzed for nitrate, 159 are in primary recharge areas, 51 are in secondary recharge areas, and 233 are in discharge areas based on Snyder and Lowe's (1998) mapping. Nitrate concentrations for primary-recharge-area wells range from less than 0.02 to 21.6 mg/L and average 3.1 mg/L. Nitrate concentrations for secondary-recharge-area wells range from less than 0.02 to 40.2 mg/L and average 3.5 mg/L. Nitrate concentrations for discharge-area wells range from less than 0.02 to 21.7 mg/L and average 3.4 mg/L. Figure 16 summarizes the percentage of wells in each hydrogeologic setting category that are below 3 mg/L nitrate concentration, between 3 mg/L and less than 10 mg/L nitrate concentration, and 10 mg/L or greater nitrate concentration. Most of the high-nitrate wells are in primary recharge areas (Wallace and Lowe, 1997).

Of the potential sources of geologic nitrogen (see appendix D) in the San Pitch River drainage basin, coal deposits are the most likely contributor. Alluvial-fan sediments deposited by streams draining the Wasatch Plateau in the Sixmile Canyon area would be the most likely units to contain coal debris in the valley fill of Sanpete Valley; less extensive coal deposits are also found in a few canyons in the San Pitch Mountains. Nitrate concentrations along the east side of Sanpete Valley are generally low. We do not attribute high nitrate concentrations in ground water from any wells to geologic nitrogen.

Agricultural fertilizer application rates are generally highest on irrigated lands (see appendix D). Of the 443 wells sampled and analyzed for nitrate, 257 are within the boundaries of irrigated lands (plate 4). Of the 147 shallow wells sampled during this study, 96 wells are within the boundaries of irrigated lands. The average nitrate concentration for all wells is 3.3 mg/L; the average nitrate concentration for wells of all depths located on irrigated lands is 2.7 mg/L. The average nitrate concentration for all shallow wells is 3.5 mg/L; the average nitrate concentration for shallow wells located on irrigated lands is 3.8 mg/L. Nitrogen-fixing crops, principally alfalfa, are grown in Sanpete Valley. Of the 436 wells sampled and analyzed for nitrate, 76 are within the boundaries of alfalfa fields (plate 5). Of the 147 shallow wells sampled during this study, 35 wells are within the boundaries of alfalfa fields. The average nitrate concentration for all

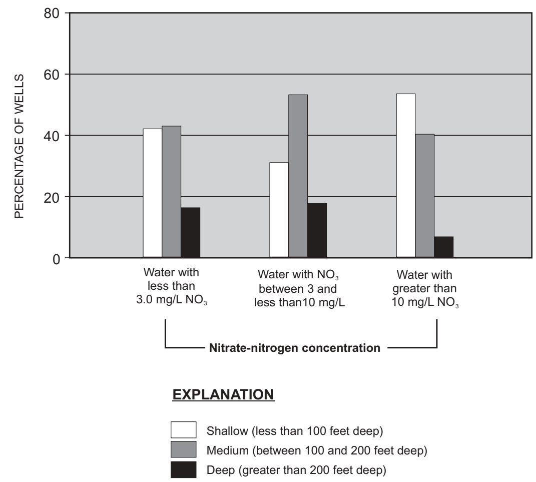


Figure 14. *Percentage of wells in each shallow, medium, and deep perforation-depth interval that are less than 3 mg/L, between 3 and less than 10 mg/L, and greater than 10 mg/L nitrate concentration in Sanpete Valley, Sanpete County, Utah.*

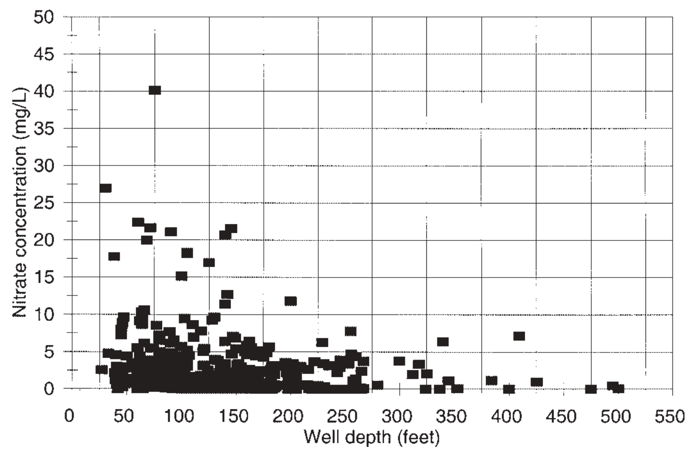


Figure 15. *Well depth versus nitrate concentration, Sanpete Valley, Sanpete County, Utah. Correlation coefficient is -0.16 (R-squared is 0.026).*

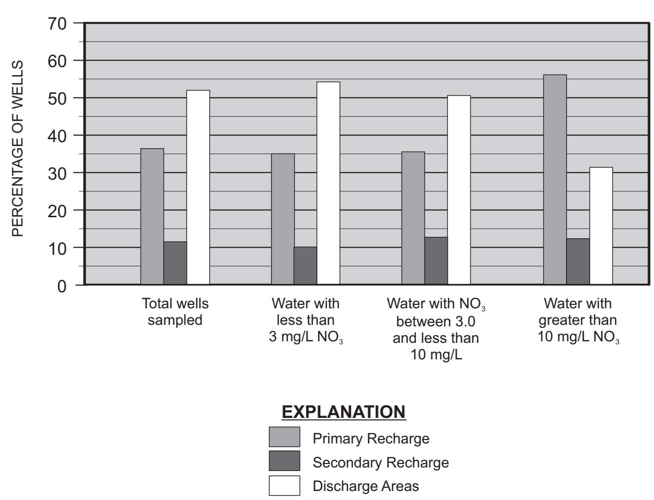


Figure 16. *Percentage of wells in each hydrogeologic setting category that are less than 3 mg/L, between 3 and 10 mg/L, and greater than 10 mg/L nitrate concentration in Sanpete Valley, Sanpete County, Utah.*

wells is 3.3 mg/L; the average nitrate concentration for wells of all depths located on alfalfa fields is 3.0 mg/L. The average nitrate concentration for all shallow wells is 3.5 mg/L; the average nitrate concentration for shallow wells located on alfalfa fields is 4.2 mg/L. These values suggest that agricultural fertilizer application rates in Sanpete Valley likely do not impact water quality with respect to nitrate.

Animal feed-lot operations and other concentrations of domestic animals are common in Sanpete Valley (plate 2, appendix A). Most of these domestic animal operations in Sanpete Valley are turkey production facilities (table 5, appendix A); turkeys and other poultry produce the highest amount of nitrate per pound of manure for common domestic animals (appendix D, table D3). A comparison of plate 1 and plate 2 demonstrates that all but two of the high-nitrate areas are in the general vicinity of domestic farm animal operations. However, most domestic farm animal operations are located in areas where ground water has low nitrate concentrations. Figure 17 shows the average nitrate concentration for each perforated-interval-depth category for wells that are within 0.25 miles (0.4 km) of current or former animal feeding operations versus wells in each depth category that are more than 0.25 miles (0.4 km) away from animal feeding operations; wells within 0.25 miles (0.4 km) of current or former animal feeding operations have higher average nitrate concentrations for all perforation depth categories than wells more than 0.25 miles (0.4 km) away from former or current animal feeding operations (figure 17). These data indicate that most high-nitrate-concentration wells are situated closer to animal feeding operations than overall lower nitrate concentration wells. This is especially evident for shallow wells (less than 100 feet deep).

Septic-tank systems are known sources of nitrate contamination. Because septic-tank systems are below ground, we were not able to map their locations on plate 2. Since 1981, about 150 wastewater permits have been issued each year in Sanpete Valley (George Johansen, verbal communication, 2000). Outside of towns and cities, septic-tank systems in Sanpete Valley, until recently, have been widely spaced. However, the towns and cities initially used septic-tank systems, cesspools, or privies for wastewater disposal. In some situations, old abandoned wells were used as cesspools (Richardson, 1907). These domestic wastewater facilities could have contributed to high nitrate concentrations in ground water in the vicinity of the towns and cities. If so, high-nitrate-concentration ground water in the vicinity of towns and cities could be areally extensive. We were able to sample wells within or immediately downgradient from only two of the towns or cities, Moroni and Chester. In both areas, ground water yielded high nitrate concentrations. Septic tanks also can produce relatively high concentrations of total dissolved solids, but this is likely not the case in Sanpete Valley; wells having high nitrate concentrations associated with septic tanks (table 9) have total-dissolved solids concentrations below 800 mg/L (plate 6). Figure 18 shows the relationship between nitrate and total-dissolved-solids concentrations with a correlation coefficient of 0.4; this indicates a non-correlative relationship.

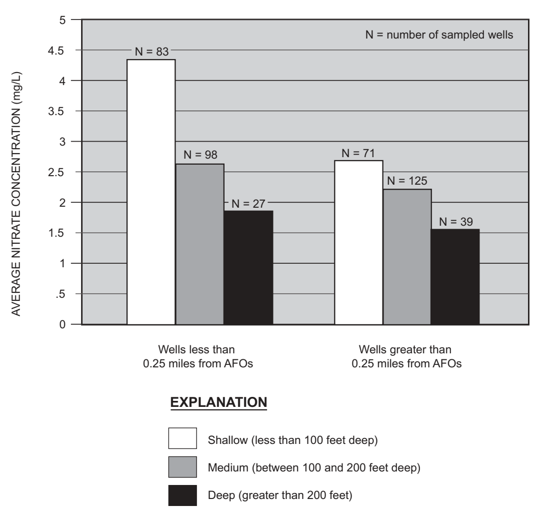


Figure 17. *Average nitrate concentration for shallow, medium, and deep perforation-depth intervals for water wells less than or equal to 0.25 miles (0.4 km) and greater than 0.25 miles (0.4 km) from existing or former animal feed-lot operations (AFOs) in Sanpete Valley, Sanpete County, Utah.*

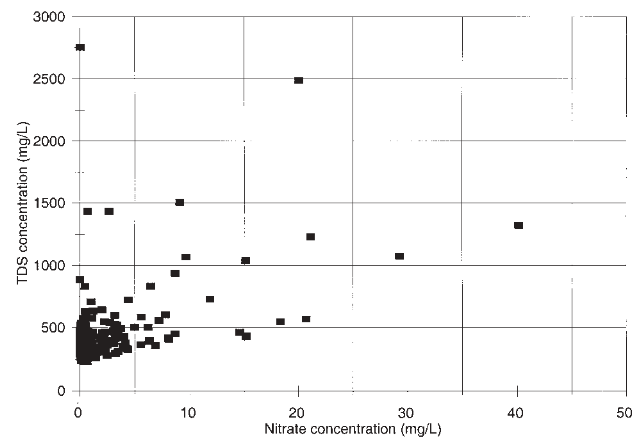


Figure 18. *Nitrate concentration versus total-dissolved-solids (TDS) concentration for ground water for 118 wells in Sanpete Valley, Sanpete County, Utah. Correlation coefficient is 0.4 (R-squared is 0.016).*

Other Chemical Constituents

Utah drinking-water standards were exceeded for lead in ground water from two wells, arsenic in ground water from two other wells, and for copper in ground water from one well (figure 19). These wells were resampled during fall of 1999 and reanalyzed for the constituents exceeding drinking-water standards (table 1); two of the resampled wells yielded ground water that exceeded drinking-water standards for arsenic (figure 19). Of the water wells tested for pesticides, seven wells yielded ground water having values above the detection limit, but at levels below Utah drinking-water standards (figure 19).

Field Review of Wells Yielding Ground Water with High Nitrate Concentrations

The 16 wells that yielded ground water with high nitrate concentrations during the initial sampling phase were field checked on August 27, 1997, to determine well condition and likely sources of the nitrate. Participants in the field review included Gary Anderson, Ephraim Mayor/Utah State Agricultural Extension Agent; Roger Foisy, Utah Department of Environmental Quality District Engineer; Bill Damery, Utah

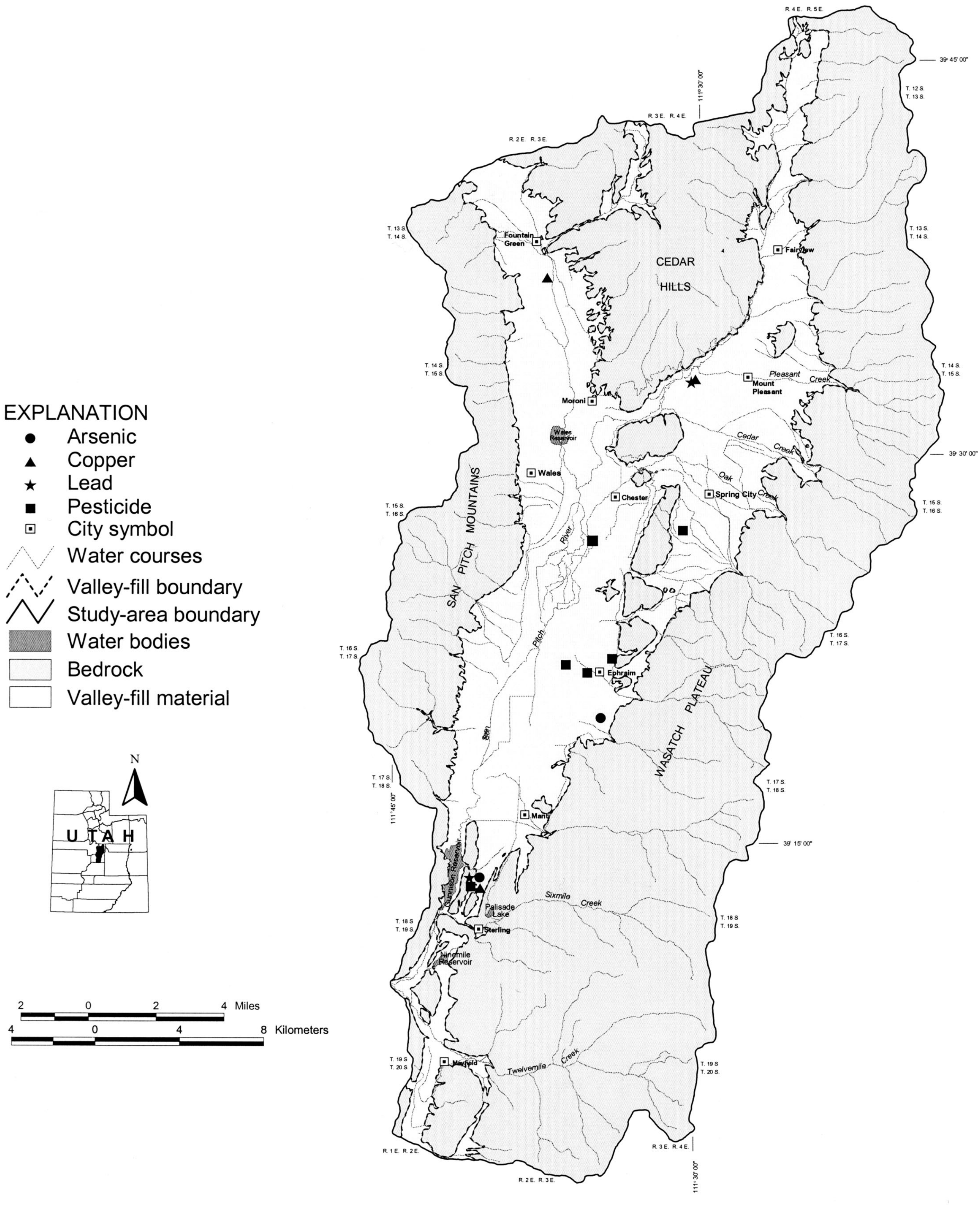


Figure 19. Distribution of wells having ground-water constituents that exceed water-quality standards, and pesticides above maximum reporting level but below water-quality standards in Sanpete Valley, Sanpete County, Utah..

Division of Water Quality; Mark Quilter, Utah Department of Agriculture and Food; and Charles Bishop, Mike Lowe, and Janae Wallace, Utah Geological Survey. Table 9 summarizes the consensus regarding well condition and likely nitrate sources concluded from participants of the field reconnaissance. Poor well condition is likely responsible for water-quality degradation in several instances. No single category of potential nitrate source is considered the major cause of water-quality degradation. The evaluation of our nitrate data above corroborates the conclusion that multiple sources contribute nitrate to ground water in Sanpete Valley.

Extent of Areas with High Nitrate Concentrations

Data indicate about half of the high-nitrate wells are impacted by diffuse non-point sources, not nitrate plumes. Other areas where wells have elevated nitrate concentrations lack sufficient chemistry data to determine the nature of the ground-water conditions. These conclusions are based on the results of Piper plots used to analyze and compare chemistry of individual high-nitrate wells.

We generated individual Piper plots for areas in the valley having elevated nitrate concentration to assess whether a correlation between general chemistry type and nitrate concentration exists. Figure 20 shows the locations of these Piper plot analyses. A positive correlation between conservative constituents (relatively non-reactive cations) and relatively mobile nitrate may indicate that the high-nitrate ground water in two or more wells is from a common source. No strong correlation between nitrate concentrations and total-dissolved-solids concentrations exists (figure 18); although some wells having high nitrate concentration also have elevated total-dissolved-solids concentrations in the valley, wells having low nitrate concentrations (less than 2 mg/L) and elevated total-dissolved-solids concentrations (greater than 1,000 mg/L) are common, especially in the southern and east-central parts of the valley (figure 13).

In the northwest part of Sanpete Valley, just north of the town of Moroni, several wells have yielded ground water with elevated nitrate concentrations both from previous studies (appendix C, table C6) and in this study. A Piper plot of data from nine wells (figure 21) indicates similar water quality. Well depths range between 82 and 151 feet (25-46 m), and are located in primary or secondary recharge areas (plates 9 and 10). Four of the wells are less than or equal to 100 feet (30 m) deep and four of the wells are between 100 and 200 feet (30 and 61 m) deep. Total-dissolved-solids concentrations range from 350 to 572 mg/L, with an average of 439 mg/L. Four of the wells, during different seasons and years, have consistently yielded nitrate concentrations that exceed the Utah drinking-water standard. These wells are generally upgradient from the other wells having similar water quality but lower nitrate concentrations. Both upgradient and downgradient wells likely penetrate the same aquifer, so the lower nitrate values for the wells downgradient may be due to dilution or because the high-nitrate ground water has not reached them. We interpret this area as having a potential for ground-water mixing based on consistent and persistent elevated nitrate concentration in three water wells coupled with established land-use practice and poor well condition (table 9).

A Piper plot of data from eight wells around Mt. Pleasant (figure 22) indicates similar water quality and the potential for ground-water mixing. Well depths are between 85 and 325 feet (26 and 99 m), and are located in the primary recharge area (plates 9, 10, and 11). One well is less than 100 feet (30 m) deep, two are between 100 and 200 feet (30 and 61 m) deep, and two wells are greater than 200 feet (61 m) deep. Total-dissolved-solids concentrations range from 296 to 466 mg/L, with an average concentration of 366 mg/L. Only one well has an elevated nitrate concentration and is located both upgradient and downgradient from the other wells plotted on the diagram. The similar water quality, variable depths, and variable nitrate concentrations neither support nor negate the possibility of ground-water mixing, and the well having the high nitrate concentration, as tested over different years, may represent an isolated, non-mixing scenario.

A Piper plot of data from nine wells due west of the town of Moroni and south of Fountain Green (figure 23) indicates similar water quality and possible ground-water mixing. Well depths range between 89 and 475 feet (27 and 145 m), and are located in the discharge area. Four of the wells are less than 100 feet (30 m) deep, one is between 100 and 200 feet (30 and 61 m) deep, and one well is 475-feet (145 m) deep. Total-dissolved-solids concentrations range from 266 to 630 mg/L, with an average concentration of 386 mg/L. Two of the wells have nitrate concentrations that exceed 10 mg/L, and the rest are below the drinking-water standard. One well, (D-15-3)6cab-1, that was sampled multiple times and had variable nitrate concentrations (both high and low as shown in table 9) may represent two different wells due to being sampled by two different technicians. We also tested pond water in the discharge area of one of the high-nitrate flowing wells, and it had a nitrate concentration of 0.53 mg/L. For this area, as in the Mt. Pleasant area, the similar water quality, variable well depths, and variable nitrate concentrations neither support nor negate the possibility of ground-water mixing, although the low nitrate concentration in the pond water of the flowing well suggests a non-mixing scenario.

Data for nine wells in the vicinity of Moroni show a more scattered distribution and variable water quality (figure 24). Two wells with elevated nitrate concentrations located in the town proper have total-dissolved-solids concentration values that are greater than total-dissolved-solids concentration values of all the other wells shown in the Piper plot having lower nitrate concentration, also indicating differences in water quality for wells in this area. Total-dissolved-solids concentrations for the lower nitrate concentration wells plotted in the diagram range from 314 to 832 mg/L, with an average of 514 mg/L. The two wells with elevated nitrate concentrations (30 mg/L and 11 mg/L) have respective total-dissolved-solids concentrations of 1,076 and 1,508 mg/L. Well depths for all of the wells described above range from 30 feet to 425 feet (9-130 m). Three of the wells are less than 100 feet (30 m) deep, two are between 100 and 200 feet (30 and 61 m) deep, and two are greater than 200 feet (61 m) deep. The variable depth of these wells may explain variations in water chemistry, as they likely penetrate different aquifers; mixing of ground water in Moroni proper is an unlikely scenario.

Many wells, not listed above, have nitrate concentrations that exceed the drinking-water standard but do not have suf-

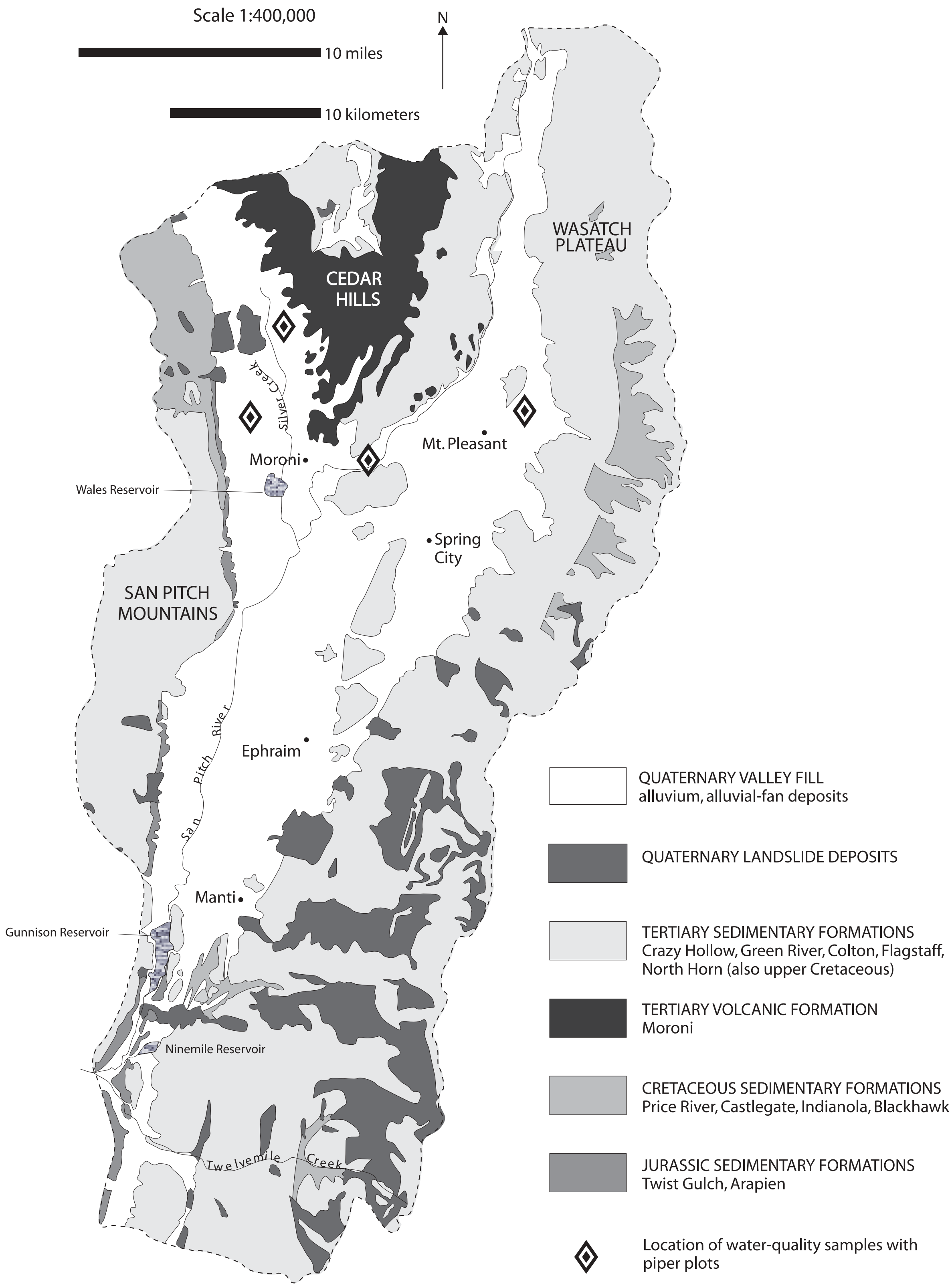


***Figure 20.** Location of areas having Piper plot analyses, Sanpete County, Utah.*

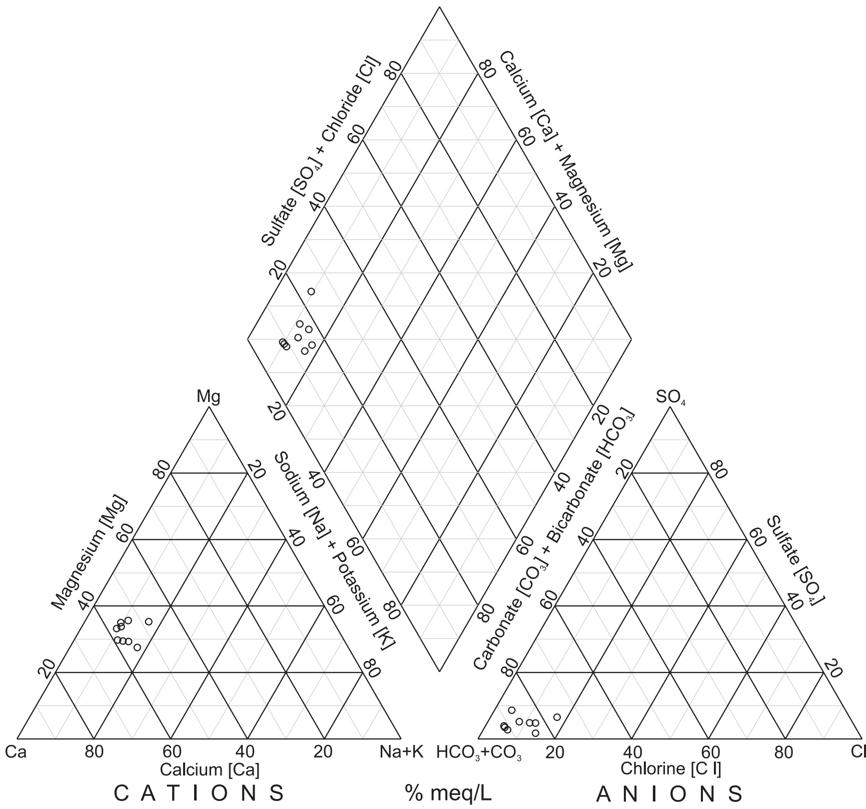


Figure 21. Piper plot of ground-water chemistry from wells north of Moroni in Sanpete Valley, Sanpete County, Utah.

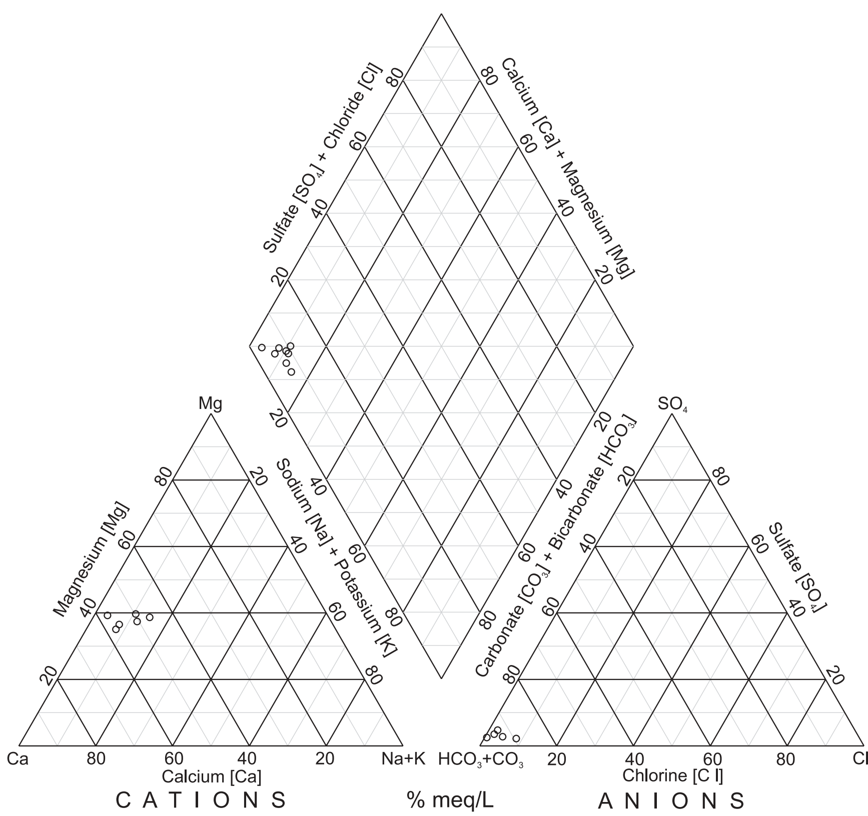


Figure 22. Piper plot of ground-water chemistry from wells near Mount Pleasant in Sanpete Valley, Sanpete County, Utah.

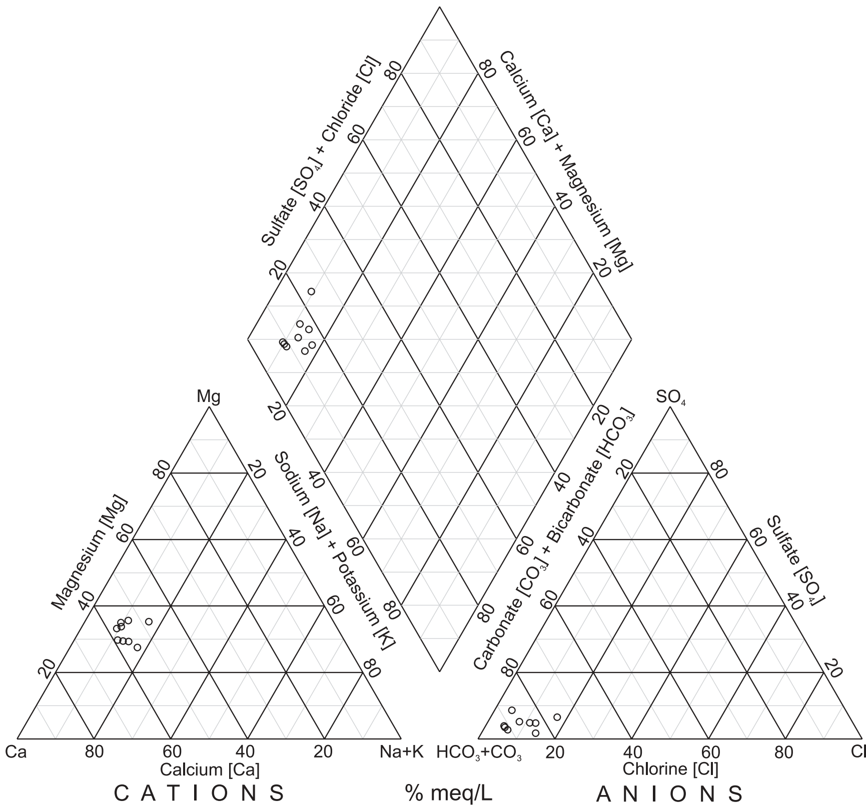


Figure 23. *Piper plot of ground-water chemistry from wells west of Moroni and south of Fountain Green in Sanpete Valley, Sanpete County, Utah.*

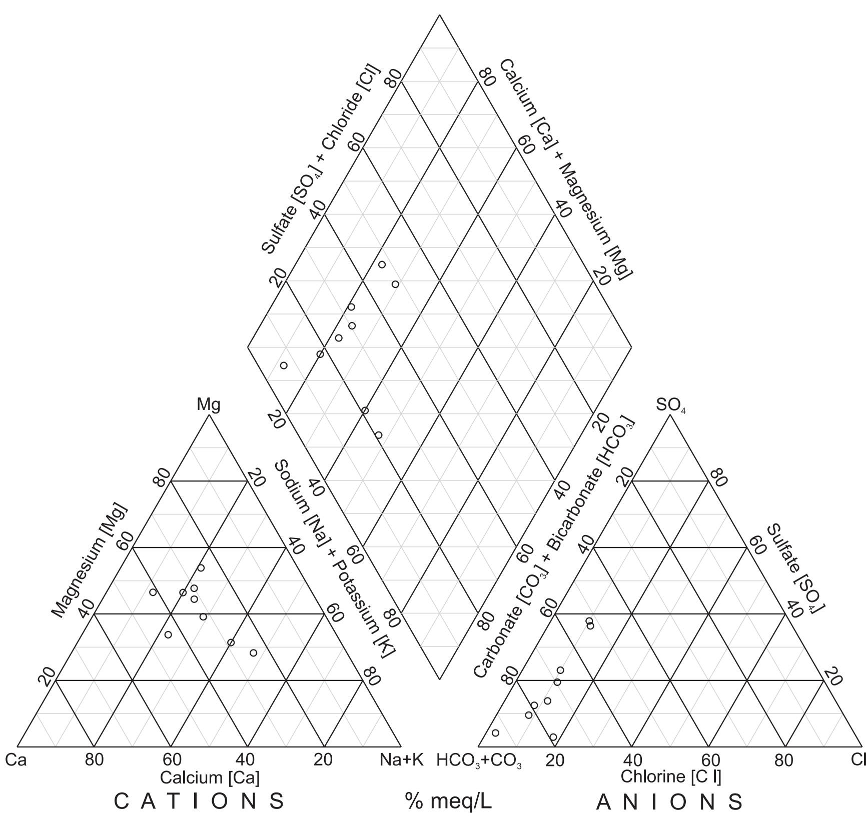


Figure 24. *Piper plot of ground-water chemistry from wells in Moroni proper in Sanpete Valley, Sanpete County, Utah.*

ficient data from the wells themselves nor nearby wells to determine an areally extensive ground-water contamination or single-well impacts. In other areas, high-nitrate wells are surrounded by low-nitrate wells, and probably represent single-well contaminations.

Age of Nitrate-Impacted Ground Water based on Tritium Analysis

Tritium (H^3) provides a qualitative age of ground water for determining the relative time when water entered the ground-water system. Tritium is an unstable isotope of hydrogen having a half-life of 12.3 years; tritium concentration in ground water isolated from other water will decrease by one-half after 12.3 years. The relatively short half-life of tritium makes it an excellent indicator of recent ground-water recharge and relative ground-water age. Tritium occurs naturally in the atmosphere, but above-ground nuclear testing from 1952 to 1969 added tritium to the atmosphere in amounts that far exceed the natural production rates, and, as a result, tritium concentrations in precipitation also increased. The amount of tritium in the atmosphere from weapons testing probably peaked in the early to mid-1960s, and has been declining since atmospheric nuclear testing ceased. Modern concentrations are typically between 20 and 50 tritium units (TU). Tritium in the atmosphere incorporates into water molecules and enters the ground-water system as recharge from precipitation. Because tritium is part of the water molecule, it is not affected by reactions other than radioactive decay, and thus can be used as a tracer of ground water on a time scale of less than 10 to about 50 years before present. Water that entered the ground-water system before 1952 and has remained isolated from younger water contains no detectable tritium, and is interpreted to have recharged before 1952. Therefore, tritium can be used to distinguish between water that entered an aquifer before 1952 and water that entered the aquifer after 1952.

On August 23, 2000, we collected water samples for tritium analysis from three wells in northern Sanpete Valley having high nitrate concentrations (figure 25, table 10). Tritium concentrations measured in ground water from these three wells with shallow to medium-depth perforations range from about 151.5 to 193.8 TU. The samples were tested for tritium content by direct liquid scintillation counting. The values we report indicate that at least some of the water must have been recharged when the tritium levels were greater than 1,000 TU. Tritium concentrations in the wells suggest that some water in the wells was recharged on the order of 40 years ago (post-atmospheric testing) when tritium concentrations in the atmosphere were near peak levels. While some ground water in an area can be older than the estimated minimum age, but younger than pre-1952 water, due to mixing with younger, lower tritium ground water, these data represent a post-atmospheric testing age for ground water entering the aquifer system before traveling to the well. These estimated ages are consistent with the flow pattern and ground-water velocity interpretation provided below in this report; ground water in the areas sampled for tritium flows at relatively low flow velocities, and does not travel far before reaching the sampled wells (see section below "Advective-Flow Particle Tracking" for rate and distant results).

Table 10. *Tritium concentration (in Tritium Units, TU) in ground water from well samples collected on August 23, 2000, in Sanpete Valley, Sanpete County, Utah.*

Well location	Tritium concentration (TU)	Tritium error (TU)
(D-14-3) 20 aba-1	193.8	± 69.6
(D-15-3) 10 dad-1	151.5	± 69
(D-15-3) 35 dda-1	163.5	± 69

CONTAMINANT TRANSPORT MODELING

Computer Modeling

We used a three-dimensional, finite-difference, numerical model of ground-water flow for the valley-fill aquifer system in Sanpete Valley to provide cell-to-cell flow data to help determine ground-water flow directions and to perform particle-tracking analysis. We employed Wilberg and Heilweil's (1995) MODFLOW model to determine steady-state ground-water flow for the aquifer system in Sanpete Valley, and used the GMS ground-water modeling system to implement the model of Wilberg and Heilweil (1995) to determine ground-water flow directions and the particle-tracking analysis. We apply their model as it provides the best available representation of the Sanpete Valley valley-fill aquifer, and influences the particle-tracking analysis. The model uses water levels and other components to estimate ground-water flow; it uses calibrated, measured, and estimated components of a ground-water budget with measured water levels. The measured budget components include: (1) the San Pitch River seepage during March and April, 1966, and October, 1988; (2) average annual pumped-well withdrawals from 1963 to 1988; (3) flowing-well discharges from 1965 to 1967; and (4) spring discharge from 1965 to 1967. The particle-tracking program used in this investigation was the USGS three-dimensional, particle-tracking post-processor MODPATH developed by Pollock (1989, 1994) and implemented in the GMS ground-water modeling system.

The objectives of the particle-tracking analysis were to: (1) simulate the advective transport of nitrate in the ground-water system, (2) determine travel times in the ground-water system, and (3) characterize and illustrate ground-water flow paths (areas contributing ground water) to selected wells in Sanpete Valley. The particle-tracking analysis of ground-water flow in Sanpete Valley's aquifer system was performed for two scenarios: (1) the results of the steady-state simulation and a single value of effective porosity for each model layer based on Wilberg and Heilweil (1995), and (2) the results of the steady-state simulation and an empirical relationship between hydraulic conductivity and effective porosity; we derived an effective porosity distribution for Sanpete Valley's aquifer system based on an empirical relationship between hydraulic conductivity and effective porosity for 166 wells, from which both parameters were estimated (hydraulic conductivities were estimated from specific capacity tests on the 166 wells and effective porosities were estimated from the hydraulic conductivities). We simulated ground-water flow paths within the aquifer system at 15 sites within Sanpete Valley.

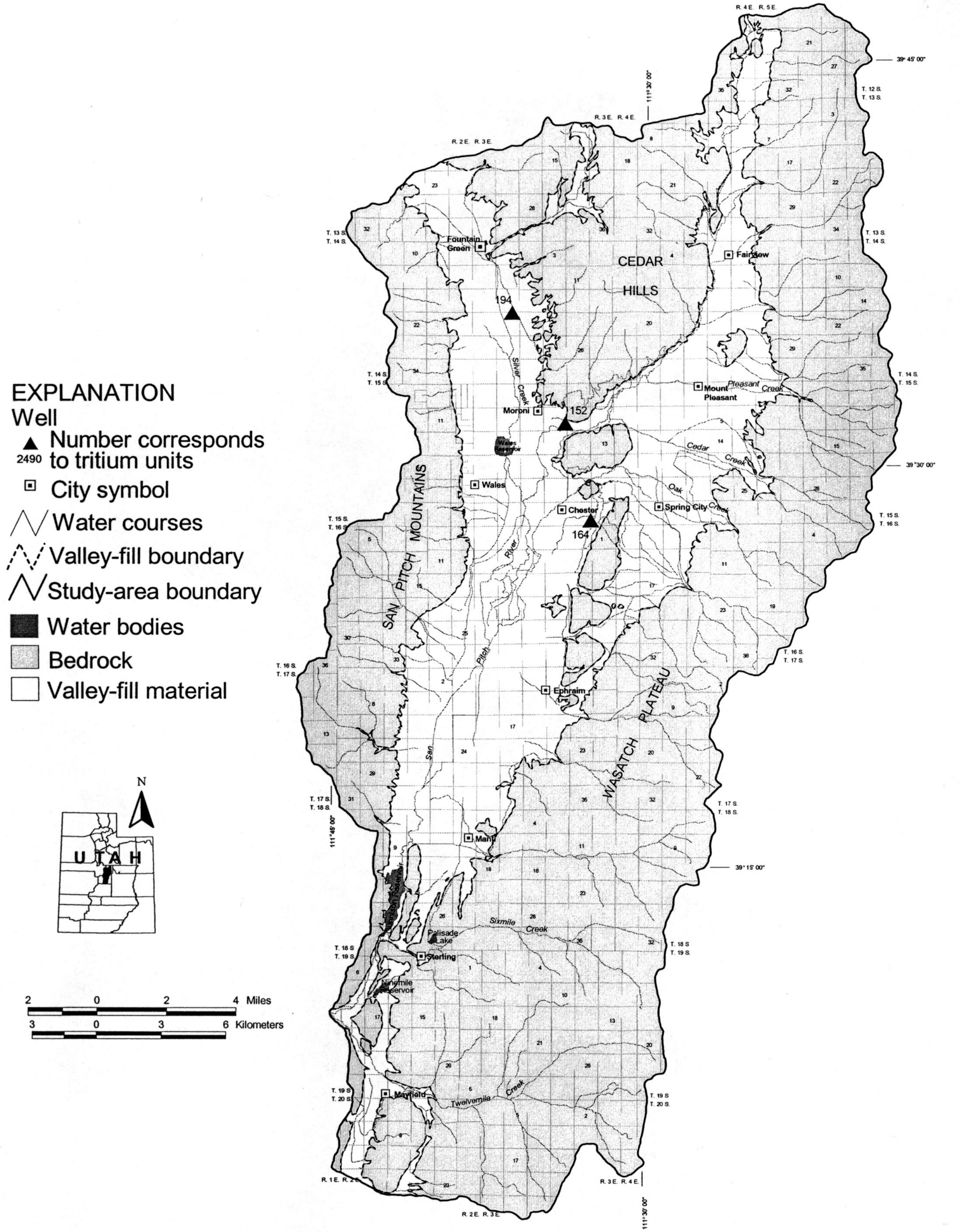


Figure 25. Location of wells sampled for tritium in Sanpete Valley, Sanpete County, Utah.

Particle-Tracking Analysis

Description of Wilberg and Heilweil's (1995) Model

Wilberg and Heilweil (1995) used the U.S. Geological Survey modular three-dimensional, finite-difference, ground-water flow simulator (MODFLOW) (McDonald and Harbaugh, 1988) to test and refine their conceptual understanding of the flow system in Sanpete Valley. Their model discretizes the valley-fill aquifer into a quasi-three-dimensional grid of 80 rows by 40 columns, with three layers. The model uses a vertical leakance term between layers, and assumes two-dimensional horizontal flow in the aquifer and one-dimensional vertical flow.

The model's rectilinear grid has a uniform grid-cell spacing of 0.5 miles (0.8 km) resulting in a cell area of 0.25 square miles (0.65 km^2). The y-axis of the model is oriented north-south, parallel to the primary surface-water drainages and predominant direction of ground-water flow (figure 26). The rectilinear grid consists of 896 active cells in layer one, 697 active cells in layer two, and 307 active cells in layer three. Layer one represents an area of 224 square miles (580 km^2) and represents the shallow unconfined aquifer which consists of approximately the upper 50 feet (15 m) of saturated valley-fill material. Layer one simulates no discharge from wells, only the discharge from springs. Layer two represents saturated valley-fill material from 50 to 150 feet (15-46 m) depth, which is semi-confined and represents an area of 174.25 square miles (451.31 km^2). Most of the water wells in the valley are simulated in model layer two.

Layer three represents a confined aquifer with saturated valley-fill material deeper than about 150 feet (46 m) and covers an area of 76.75 square miles (198.78 km^2); some wells are simulated in this model layer. The active cells in the model represent most of the Sanpete Valley unconsolidated aquifer, including both northern arms, where the Quaternary-age valley-fill material is more than 50 feet (15 m) thick (figure 27). Inactive cells are not part of the solution, but use up storage space in the arrays and represent bedrock (which is not modeled) (figure 26).

Wilberg and Heilweil (1995) initially estimated hydraulic parameters based on single-well specific-capacity tests, a few multiple-well aquifer tests, and data from Robinson (1971). Hydraulic conductivity values from these sources range from about 6 to 99 feet per day (2-30 m/d). Initially Wilberg and Heilweil (1995) used a uniform hydraulic conductivity value for layer one of 50 feet per day (15 m/d). Transmissivity values reported for the valley-fill sediments, used in layers two and three, range from 500 to 16,000 square feet per day (50-1,500 m^2/d). During the steady-state calibration of the model, input parameters were systematically varied and refined to a non-uniform distribution (table 11). The steady-state simulation assumes the water flowing into the ground-water system equals the amount flowing out with no change in ground-water storage with time. For layer one, this distribution ranged from 0.2 to 50 feet per day (0.06-15 m/d) to achieve a best fit between simulated and observed data (measured water levels and components of the ground-water budget). The initial value of transmissivity used for layers two and three was 10,000 square feet per day (930 m^2/d). Wilberg and Heilweil (1995) subsequently modified these values to a non-uniform distribution ranging from 100 to 10,000 square feet per day (9.3-930 m^2/d) for layer two and 2,000 to 20,000 feet squared per day (186-1,860 m^2/d) for layer three. Transmissivity values for layers two and three are smallest along the valley edge and increase basinward. The vertical leakance used to represent confining units in the model were calculated based on the vertical hydraulic conductivity determined by comparing simulated vertical-head differences between layers. Cells in layer one with spring discharge are assigned an increased vertical conductance.

Boundary conditions for the Sanpete Valley model were based on a simplified hydrologic model. Wilberg and Heilweil (1995) specified the lateral boundaries surrounding the active cells of the model as "no-flow" boundaries by assuming they coincided with low-permeability bedrock, except for five head-dependent cells north of Fairview in layer one which simulate subsurface inflow from the valley-fill aquifer north of Fairview. The upper boundary of the model is a specified-flux boundary formed by using recharge, well, evapotranspiration (ET), and drain packages of MODFLOW to simulate the infiltration and discharge of ground water. The lower boundary of the model is a no-flow boundary.

In the model, recharge of the Sanpete Valley valley-fill aquifer occurs: (1) where perennial streams emerge from canyons to flow across coarse-grained deposits along the margins of the valley, allowing water to infiltrate readily to the underlying ground-water system, (2) where infiltration of unconsumed irrigation water and precipitation occurs, (3) from the upper reaches of the San Pitch River, and (4) from subsurface inflow north of Fairview. Alluvial fans adjacent to the Wasatch Plateau are important recharge areas. Fourteen perennial streams enter the valley and flow toward the San Pitch River; eleven of these are from the Wasatch Plateau and three are from the San Pitch Mountains. These tributaries contribute to the surface and subsurface water supplies. Before the time of large-scale irrigation, infiltration from streams flowing across the fans was probably the main source of ground water; now, the infiltration of unconsumed irrigation water is almost as important. Estimated recharge over the modeled area of Sanpete Valley from these sources ranges from 74,000 to 103,000 acre-feet per year (91-127 hm^3/yr) (Wilberg and Heilweil, 1995) (see appendix C, table C2). Ground-water discharge in Sanpete Valley is primarily from: (1) evapotranspiration in the marshes and wetlands, (2) seepage to the San Pitch River, and (3) withdrawals from wells and springs. The largest component of ground-water discharge in Sanpete Valley is evapotranspiration. Estimated discharge from the Sanpete Valley aquifer ranges from 76,000 to 224,000 acre-feet per year (94-275 hm^3/yr) (Wilberg and Heilweil, 1995) (appendix C, table C2).

Ground-Water Flow Directions

We used Wilberg and Heilweil's (1995) ground-water flow model of Sanpete Valley to determine the direction of ground-water movement. Steady-state ground-water flow vectors from the model show that the distribution of recharge and discharge areas and hydraulic characteristics of sediments control the direction and magnitude of ground-water movement (figure 28). Because the model assumes no subsurface inflow from the fractured rock surrounding Sanpete Valley, and transmissivities assigned by Wilberg and Heil-

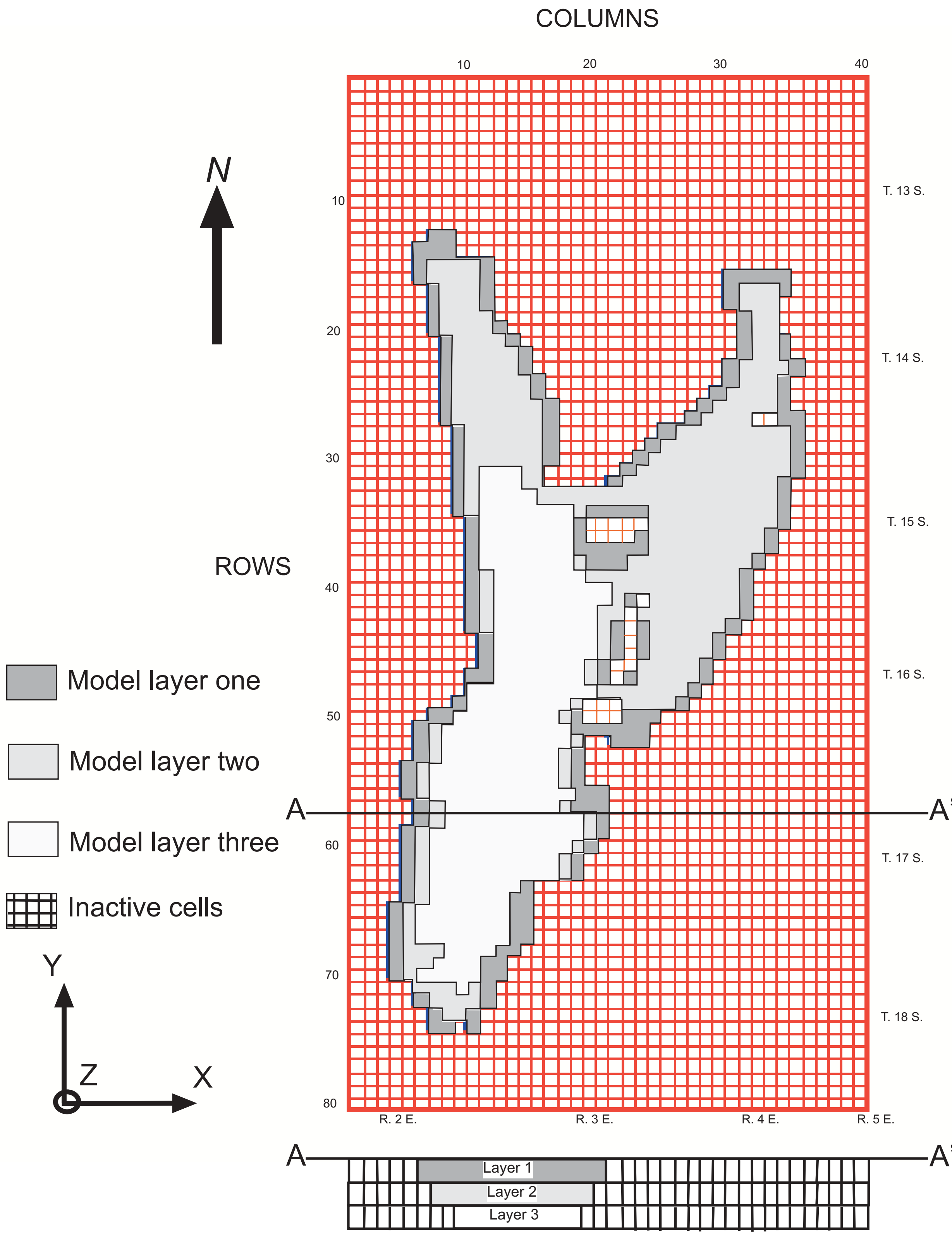


Figure 26. *Orientation and areal extent of ground-water flow model and active cells within a layer for Sanpete Valley, Sanpete County, Utah.*

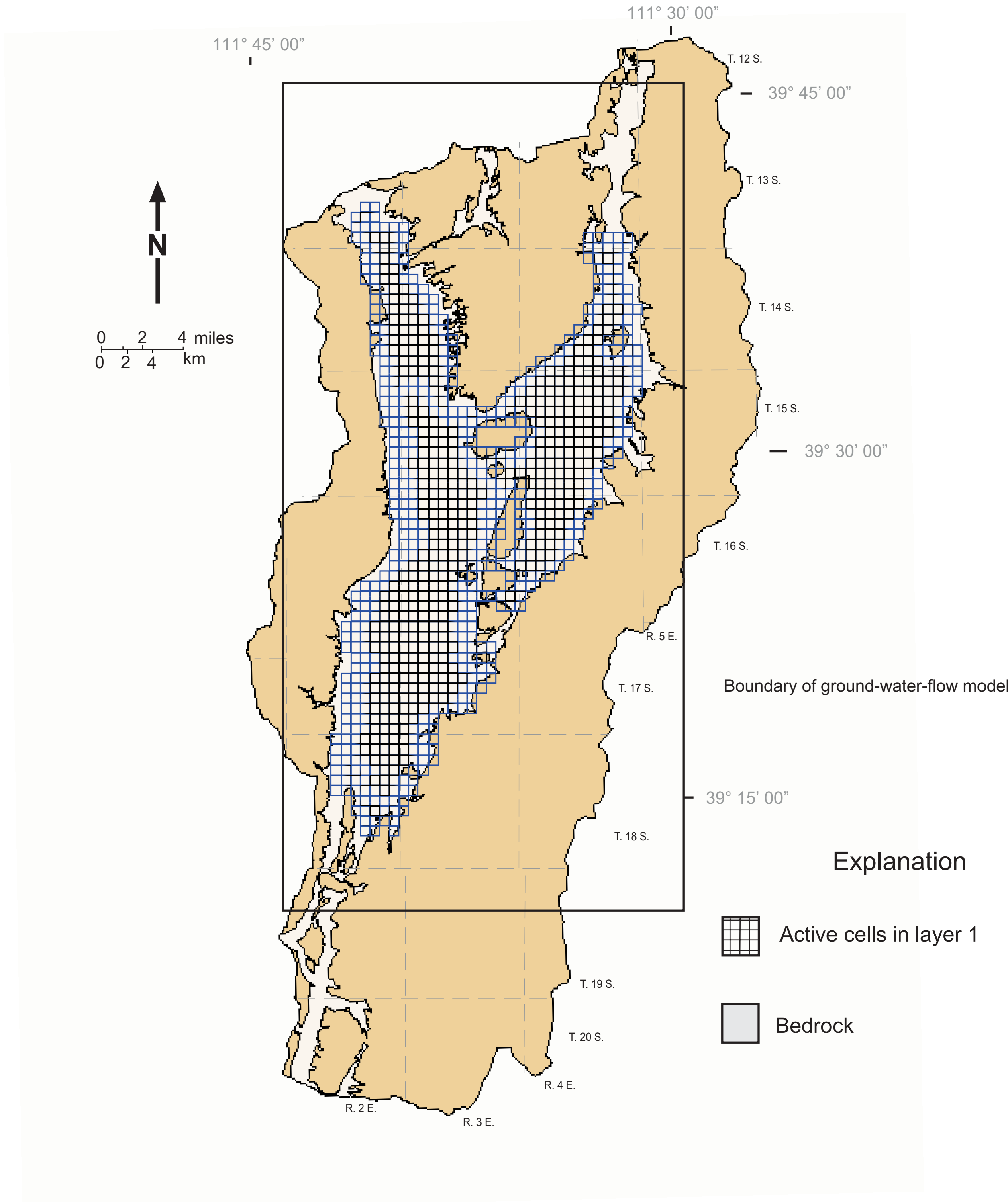


Figure 27. *Location of ground-water flow model in relation to the valley-fill boundaries. Shown are the active cells of layer one and the boundary of the model for Sanpete Valley, Sanpete County, Utah.*

Table 11. Hydraulic-parameter values used in the Sanpete Valley ground-water flow model, Sanpete County, Utah (based on data from Wilberg and Heilweil, 1995).

Locations and Layers	Hydraulic Conductivity (feet per day)	Transmissivity (feet squared per day)	Vertical leakance (feet per day per feet)
Model layer one			
Active cells around most of the perimeter of valley	2.5-10.0	-	-
Interior active cells in the main and arms of valley	15.0-50.0	-	-
Active cells around Wales	0.2-1.0	-	-
Between layers one and two			1.0×10^{-4}
Between layers one and two, where there is spring discharge in layer one			1.0×10^{-3}
Model layer two			
Active cells in the perimeter of valley	-	100-1,000	-
Active cells in the center of valley	-	10,000	-
Between layers two and three			1.0×10^{-2}
Model layer three			
Active cells at some isolated location along the perimeter of valley	-	2,000	-
Most of the active cells	-	20,000	-

weil (1995) to the ground-water flow model along the margins of the valley are smaller than transmissivities assigned in the center of the valley, flow is slower along the valley margins as compared to the interior (indicated by the relatively short arrows in figure 28). Ground water enters the system in recharge areas along the valley margin, moves slowly horizontally and downward in these areas toward discharge areas, and finally moves upward to discharge to the surface or river. Plate 12 represents the general ground-water flow direction and velocity in the valley-fill aquifer based on the Wilberg and Heilweil (1995) model layer two.

Ground water in the northeast arm of the valley flows south to southwestward and converges with westward-flowing ground water (figure 28, plate 12). The magnitude of ground-water flow increases with additional water contributed from tributaries, the infiltration of unused irrigation water, and as ground water encounters sediments with higher storativities. Ground water in the northwest arm moves southeastward along the course of Silver Creek (figure 28, plate 12). The magnitude of ground-water flow increases southward due to the contribution of water added by tributaries and by encountering the greater transmissivity valley-fill sediments. In both northern arms of Sanpete Valley, flow vectors indicate that the contribution of ground water from the Cedar Hills is negligible.

Along the east-central side of the main stem of the valley, ground water flows westward toward the San Pitch River (figure 28; plate 12). Ground water flowing from the northeastern arm and east-central side of the valley passes through several narrow corridors, due to outcrops and subcrops of low-permeability bedrock in the central part of the valley. Ground-water flow vectors (figure 28) show diffraction of flow in east-central Sanpete Valley around bedrock barriers. Several ground-water divides form as the ground water moves around these barriers.

Ground-water flow velocities increase as ground water is funneled through gaps between these barriers (figure 28); some of the highest ground-water flow velocities in Sanpete Valley exist in these gaps. Ground water from the northeast arm and east-central parts of the valley converges with the ground water from the northwest arm of the valley after flowing through these gaps.

Along the western side of the valley, ground water flows from the San Pitch Mountains toward the San Pitch River (figure 28; plate 12). In the main stem of the valley, movement of ground water in the unconsolidated valley fill in the central part of the valley follows the course of the San Pitch River (figure 28; plate 12). In the Manti area, ground-water flow is northwestward toward the San Pitch River (figure 28; plate 12).

Distribution of Effective Porosity

In particle-tracking simulations to calculate travel times and velocity distribution of the ground-water flow system, we combined an effective porosity distribution with the results of the MODFLOW simulation using Wilberg and Heilweil's (1995) model. Aquifer sediment consists of a mixture of silt and clay with fine sand and gravel (Wilberg

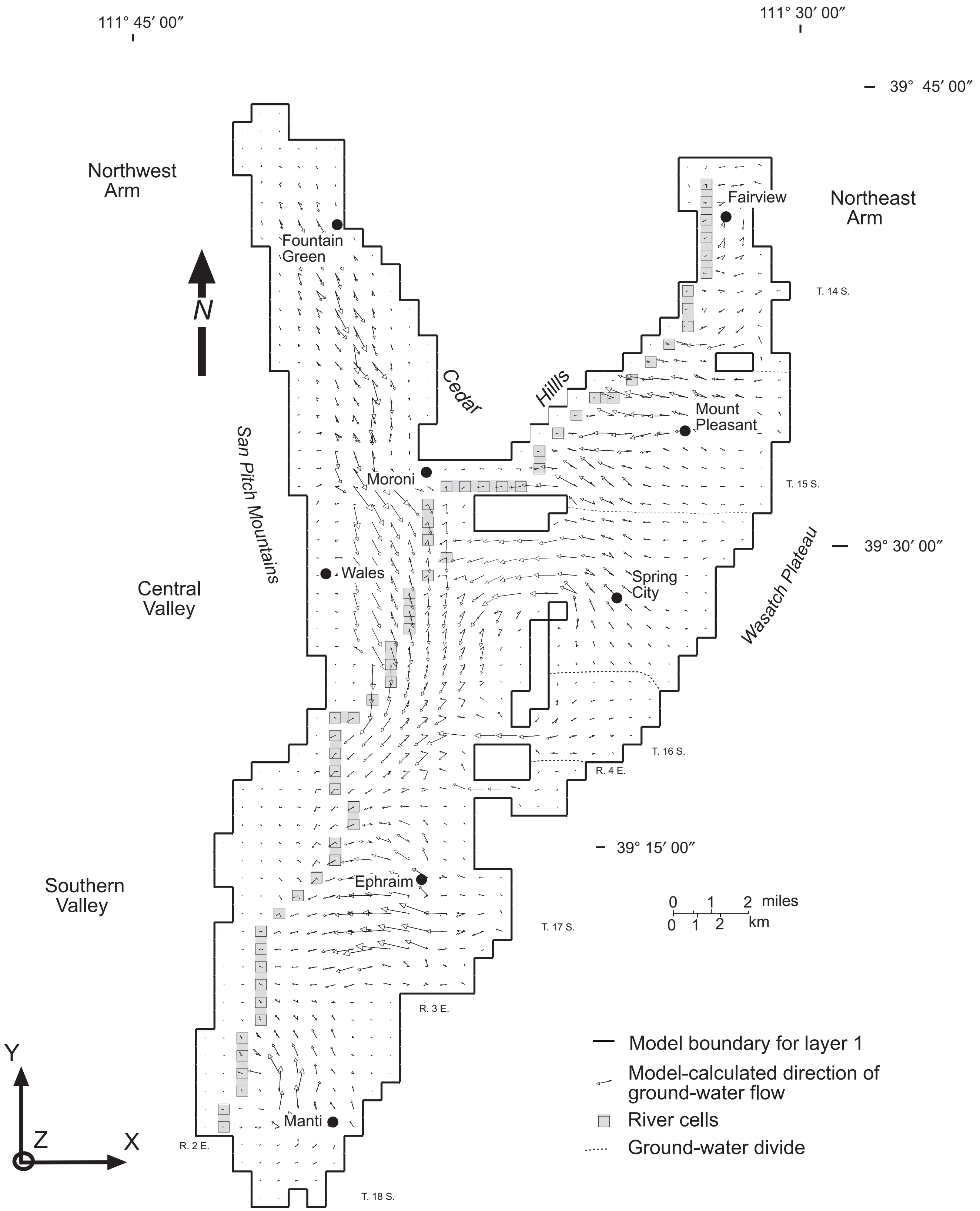


Figure 28. *Model-calculated ground-water flow directions and relative magnitude (indicated by the length of the arrow) for each element on the basis of the steady-state simulation. The flow vectors determine the regional flow pattern for Sanpete Valley, Sanpete County, Utah.*

and Heilweil, 1995). Porosity in these types of unconsolidated sediments ranges from 25 to 70 percent, with average values of about 20 to 60 percent (Freeze and Cherry, 1979). Porosity may also depend on the mode of deposition, which controls sediment sorting. Poorly sorted sediments of Sanpete Valley generally have lower porosity. We estimated the distribution of effective porosity in this study using two scenarios: (1) a single value of effective porosity for each model layer, and (2) an empirical relationship that defines a spatial distribution of porosity.

We based our single value of effective porosity on data reported in Wilberg and Heilweil (1995); they delineated layers one and two partly based on differences in specific yield and specific storage, with layer one having the lower porosity. To provide a spatial distribution of effective porosity for the hydrogeologic units that yield water to wells in Sanpete Valley, we used the method of Hinkle and Snyder (1997) who applied an empirical relation between hydraulic conductivity and effective porosity developed by Ahuja and others (1989) for particle tracking using a regional ground-water flow model in Oregon and Washington. We estimated hydraulic conductivity values and distributions for saturated sediments from 294 wells having aquifer-test data, mostly specific-capacity tests, by dividing transmissivity values by the estimated aquifer thickness at each well. Because the method used to calculate transmissivity from the specific capacity test data does not consider leakage from a confining layer, drainage from a confining layer, or well efficiency, the hydraulic conductivities determined from the aquifer tests are probably larger than the actual values. Sixty-nine wells were not used because a reasonable aquifer thickness could not be determined for them, and 59 wells were not used because they penetrate bedrock. We created an effective porosity distribution map for Sanpete Valley (figure 29) using these values and Hinkle and Snyder's (1997) method.

Advective-Flow Particle Tracking

We analyzed ground-water flow and potential movement of nitrate within the aquifer system using the calibrated model of Sanpete Valley and applying data derived from the long-term average (calibrated) recharge rate. Particle tracking simulates ground-water movement using aquifer parameters such as hydraulic gradient, hydraulic conductivity, and effective porosity to calculate a particle-flow path. The particle-tracking program also requires information defining model-layer thickness and aquifer porosity that is not explicitly incorporated in the Sanpete Valley flow model. Model-layer thicknesses are implicitly incorporated in the flow model and were entered into the particle-tracking program. Porosity was estimated for this analysis as discussed above.

We used the USGS three-dimensional particle-tracking post-processor MODPATH developed by Pollock (1989, 1994), implemented in the GMS ground-water modeling system. MODPATH incorporates cell-to-cell flow rates and water levels for all active cells calculated in the steady-state finite-difference flow simulation of Sanpete Valley. Effective porosity for each grid cell is combined with the results of the flow model by MODPATH to calculate the velocity distribution of the simulated ground-water flow system. The velocity distribution is used to determine ground-water flow paths and travel times. The effective porosity value does not affect the location of particle pathlines or the points of particle recharge; however, ground-water velocity (or more precisely, the average interstitial velocity) is inversely proportional to the effective porosity. We estimated the three-dimensional distribution of effective porosity for the model by using the empirical relation between hydraulic conductivity and effective porosity described above. MODPATH uses these to derive three-dimensional velocity fields within the model grid.

The tracking algorithm can determine particle pathlines either in the direction of flow or in the reverse direction by tracking particles backward along a flow path. The "backward tracking" option of MODPATH was used to track particles from their starting positions backwards along flow pathlines toward source areas. We computed 40-year pathlines for each particle by starting the particle at the present and ending at the 40-year travel time based on the steady-state flow model; 40 years corresponds to our estimated age of ground water based on the tritium data (the 40-year time period is partly based on the tritium data). Pathlines computed using the particle-tracking method are only as accurate as the model representation of the ground-water flow system. The MODPATH program computes particle locations and travel times in three dimensions based on advective flow in a uniformly porous medium. Physical, chemical, and biological processes that attenuate chemical constituents in ground water are not considered in an advective flow model.

We simulated ground-water flow paths within the aquifer system at 15 sites in different areas of Sanpete Valley. The sites selected for analysis correspond to 15 wells with high nitrate concentrations (figure 30 and table 9). The wells included both public-supply and private wells. These wells do not necessarily correspond to discharge cells in the ground-water flow model. We estimated travel times and source areas to the selected wells based on: (1) output from the steady-state flow model and data defining aquifer porosity that were incorporated into the particle-tracking program, (2) particles placed in model cells that simulated wells having high nitrate concentrations, described in table 12, and tracked backward from the cells toward source areas, and (3) computation of 40-year pathlines that were recorded and used to construct two-dimensional projections of the source areas.

The number of particles required to represent the source areas for the cell depends on the complexity of the ground-water flow simulation. An infinite number of possible starting positions exists for any particles that might exist in a selected model cell. More accurate results are obtained by using as many particles as possible to increase the probability of modeling all possible flow paths. This is limited by hardware and software requirements, which require the use of some subset of starting particles. During the analysis, we varied the number of particles in the model cells, within practical limits, until no substantial change in the travel times occurred. For each well location, the modeled cell was from the model layer in which the well was completed.

We ran six modeling simulations using 27, 64, 125, 216, 512, and 1,000 particles per cell in each model layer for the first porosity scenario. The particles were uniformly distributed within the cell and were tracked backwards in time, upgradient to the source, to determine the travel time. Particles were allowed to pass through cells with weak sinks

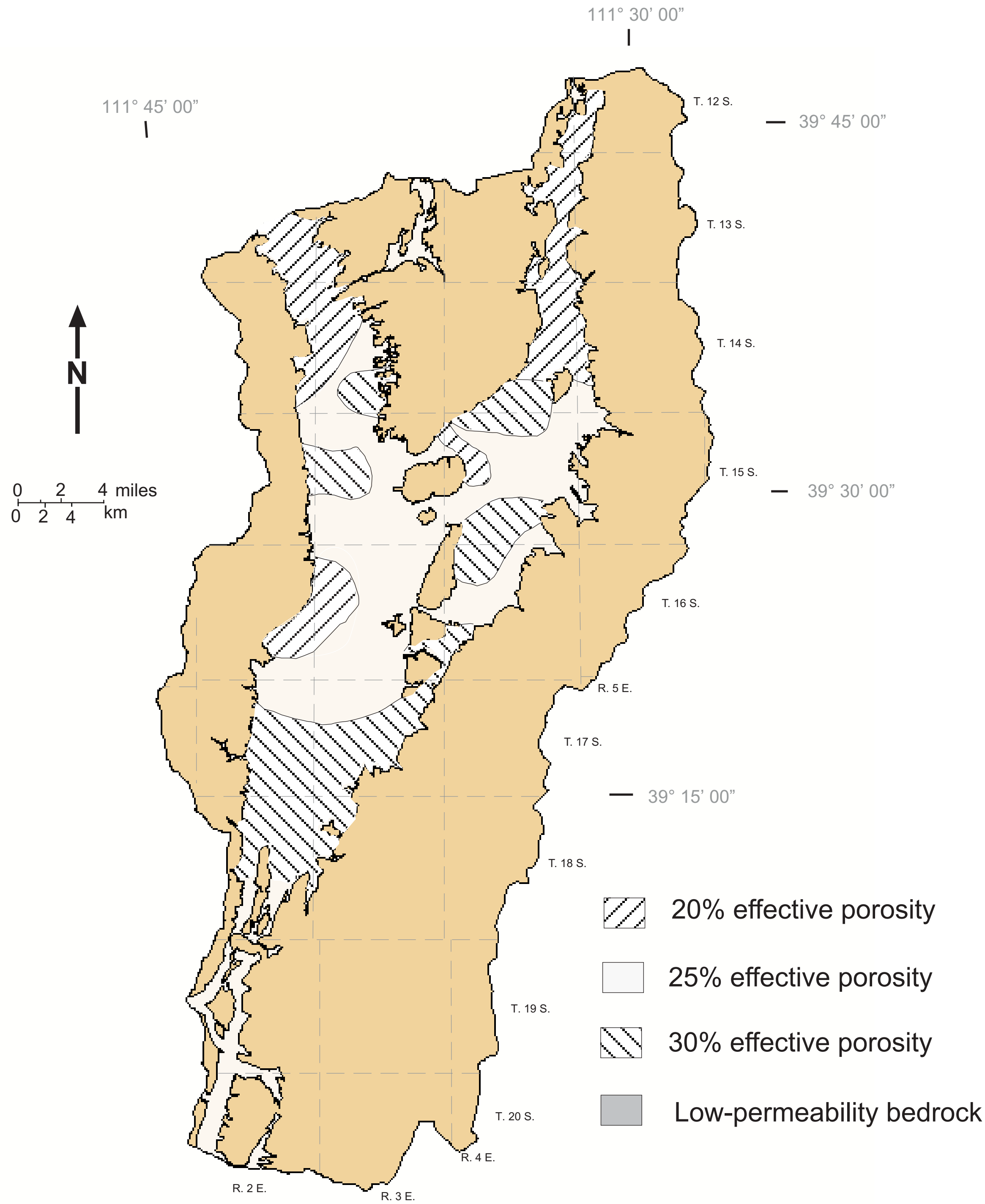


Figure 29. *Distribution of effective porosity for the unconsolidated sedimentary aquifer in Sanpete Valley, Sanpete County, Utah.*

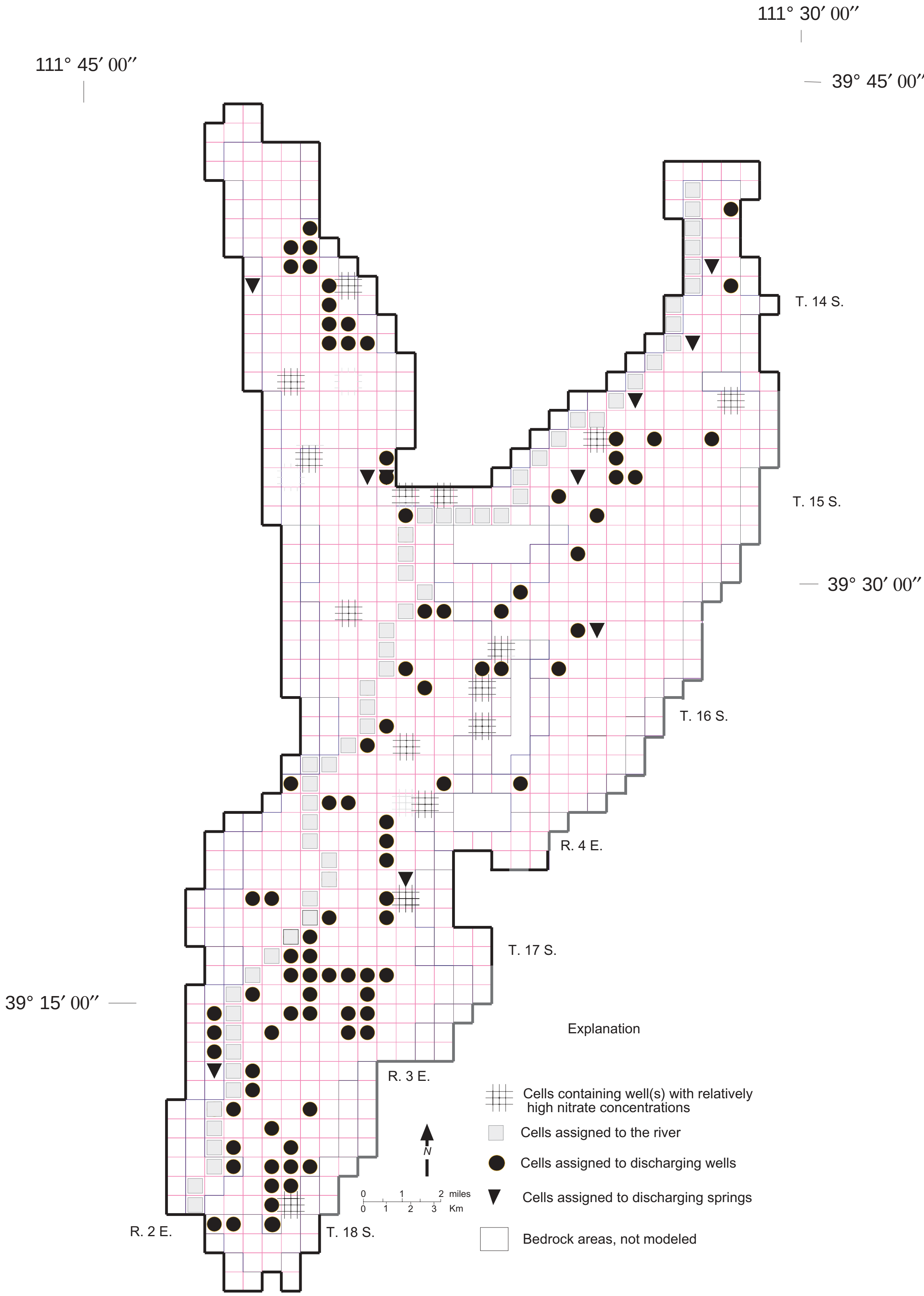


Figure 30. *Location of cells that represent wells with high nitrate concentrations. Also shown are cells that represent discharging wells and springs, and river.*

Table 12. *Cells used in the backward-particle-tracking analysis representing water wells in Sanpete Valley, Sanpete County, Utah.*

Cell ID	Model cell coordinates (row, column)	Layer	Number of wells with high nitrate concentration represented in the cell	Depth of well(s) in feet with high nitrate concentrations	Boundary affects the backward-particle tracking
1	22, 13	2	3	140, 140, and 105	yes
2	27, 10	2	1	90.5	no
3	28, 33	2	1	145	yes
4	30, 26	1	2	62 and 46	yes
5	31, 11	1	2	38 and 90.5	no
6	33, 16	1	1	30	yes
7	33, 18	1	1	70	yes
8	39, 13	1	1	47	no
9	41, 21	1	1	-	no
10	43, 20	1	1	-	no
11	45, 20	1	2	-	no
12	46, 16	2	3	145, 125, and 105	no
13	49, 17	1	1	64	no
14	54, 16	2	1	-	no
15	70, 10	2	1	-	yes

(cells having a well or spring in it), but terminated at no-flow boundaries. This allowed us to evaluate the affects of different particle densities on the distribution of travel times between the model cells and the source areas. For this report, we define a source area as the point on the surface where the particles enter the ground-water flow system. The optimum particle density was 64 particles uniformly distributed in a cell.

Plate 12 shows the backward particle-tracking results for 15 cells; the map shows the results for both porosity scenarios with entire cells representing a well or group of wells. Travel velocities for scenario one range from about 12 feet per year to almost 800 feet per year (4-244 m/yr); in 40 years, ground-water travel distances range from 480 feet to 6 miles (146 m to 10 km). However, most of the wells with high nitrate concentrations range from 12 to 26 feet per year (4-8 m/yr); in 40 years, ground-water travel distances range from 480 to 1,040 feet (146-317 m). For scenario two the travel times vary more, from almost 7 feet per year to about 1,000 feet per year (2-305 m/yr); however, all but one value was under 200 feet per year (61 m/yr). In 40 years, most ground-water travel distances range from 280 feet to less than 1.5 miles (85 m to less than 2.4 km). These data indicate that the sources of nitrate were likely relatively near the well (within 1.5 miles) yielding the high-nitrate ground water. Plate 12 also shows ground-water flow direction as generally toward the San Pitch River drainage in the basin center and south paralleling the river.

Limitations

Simplifying assumptions are required to construct a numerical model of a natural hydrogeologic system. Some of these assumptions limit the scope of application of the model and the hydrologic questions that can reasonably be addressed, and may influence the model results. Some limitations arise from the regional ground-water flow model, while others are inherent in the method of particle tracking. The degree to which the model accurately represents the actual system must be considered when interpreting the results of the particle-tracking analysis. The numerical model is a simplified and idealized approximation of the actual ground-water flow system. Wilberg and Heilweil (1995) summarize the major simplifying assumptions and their limitations on the regional ground-water flow model. We used a steady-state simulation with time-averaged and measured conditions; thus, the model cannot predict the transient response of the system, because it is not calibrated to transient conditions. This means we cannot use the model to predict flows in the system if new stresses were applied, such as adding a large well, to the system. The model, however, can simulate steady-state conditions and be used to evaluate various ground-water conditions.

GROUND-WATER QUALITY CLASSIFICATION

General

To implement appropriate best-management plans for protecting the Sanpete Valley valley-fill aquifer, we prepared ground-water quality classification maps based on the data we collected. The Utah Ground Water Quality Protection Regulations, initially adopted in 1989, contain a provision allowing the Utah Water Quality Board to classify all or parts of aquifers as a method for maintaining ground-water quality in areas where sufficient information is available. This includes having a comprehensive understanding of the aquifer system supported by factual data for existing water quality, potential contaminant sources, and current uses of ground water. Aquifer classification (or reclassification) may be initiated by either the Utah Water Quality Board or by a petition submitted by a person, company, or governmental entity. At least one public hearing is required before the Utah Water Quality Board rules on the proposed classification. Once an aquifer is classified, commensurate protection levels are applied to classified areas based on the differential protection policy.

Aquifer classes under the Utah Water Quality Board classification scheme are based largely on total-dissolved-solids (TDS) concentrations (table 13). If any contaminant exceeds Utah's ground-water-quality standards (and, if human caused, cannot be cleaned up over a reasonable time period), the ground water is classified as Class 3, Limited Use ground water. Two other classes, 1B (Irreplaceable) and 1C (Ecologically Important), are not based on ground-water chemistry and have not been considered herein.

Uses of Ground-Water Quality Classification

Aquifer classification is a planning tool for local governments to use in making land-use management decisions. It allows local governments to use potential impacts on ground-water quality as a reason for permitting or not permitting a proposed activity or land use based on the differential protection policy. Many facilities and/or activities impact ground-water quality, but are not regulated by state or federal laws. Examples of such facilities/activities include septic tanks, animal feed lots, land application of animal wastes, and some industrial/manufacturing activities. Many of these facilities/activities are permitted through local land-use management programs. From this perspective, aquifer classification can be a useful tool for local governments, if they so desire, to manage their ground-water resources based on the beneficial use established by aquifer classification.

Many potential applications exist for using aquifer classification as a land-use management tool. One example is using aquifer classification to establish zoning to locate industrial facilities in areas where ground-water quality is already poor. Additionally, aquifer classification can be used as a basis for determining the density of development in areas that use septic tanks for wastewater disposal (for example, Wasatch County, Utah, used aquifer classification as one basis for limiting septic systems to lots larger than 5 acres [2 hm]). Aquifer classification also can be used as a basis for encouraging developers to invest in the infrastructure needed to connect a proposed subdivision onto an existing sewer line, rather than dispose of domestic wastewater using septic-tank systems. However, aquifer classification does not result in any mandatory requirement for local governments to take specific actions, such as land-use zoning restrictions, technical assessments, or monitoring.

Preliminary Classification

Overall water quality is good in the Sanpete Valley valley-fill aquifer and is reflected in our preliminary ground-water quality classification, subject to approval by the Utah Water Quality Board, shown on plate 13. The classification is based on the data from the 118 wells completed in the principal aquifer which were sampled between autumn 1996 and spring 1997 by the Utah Division of Environmental Quality. Some areas, where insufficient data exist, require extrapolation of ground-water quality conditions, the basis of which depends on local geologic characteristics. The ground-water quality classes are as follows:

Class 1A - Pristine ground water: For this class, total-dissolved-solids concentrations in Sanpete Valley range from 234 to 495 mg/L. Class 1A is the predominant ground-water quality class in Sanpete Valley (plate 13). Areas having Pristine ground water cover about 65.5 percent of the total valley-fill material.

Table 13. *Ground-water quality classes under the Utah Water Quality Board's total-dissolved-solids- (TDS) based classification system (modified from Utah Division of Water Quality, 1998).*

Ground-Water-Quality Class	TDS Concentration (mg/L[3])	Beneficial Use
Class 1A/1B[1]/1C[2]	less than 500	Pristine/Irreplaceable/ Ecologically Important
Class 2	500 to less than 3,000	Drinking Water[4]
Class 3	3,000 to less than 10,000	Limited Use[5]
Class 4	10,000 and greater	Saline[6]

[1] Irreplaceable ground water (class 1B) is a source of water for a community public drinking-water system for which no other reliable supply of comparable quality and quantity is available due to economic or institutional constraints; it is a ground-water quality class that is not based on TDS.

[2] Ecologically Important ground water (class 1C) is a source important to the continued existence of wildlife habitat; it is a ground-water quality class that is not based on TDS.

[3] For concentrations less than 7,000 mg/L, the mg/L unit is approximately equivalent to one part per million (ppm).

[4] Water having TDS concentrations in the upper range of this class must generally undergo some treatment before being used as drinking water.

[5] Generally used for industrial purposes.

[6] May have economic value as brine.

Class 2 - Drinking Water Quality ground water: For this class, total-dissolved-solids concentrations in Sanpete Valley range from 506 to 2,752 mg/L. Class 2 areas are predominantly found along the western margin of the valley south of Fountain Green, along the southeastern margin of the Cedar Hills north of Moroni and along the eastern margin of the bedrock hills in the center of the valley between Moroni and Ephraim, along the eastern margin of the Wasatch Plateau north and south of Manti, throughout the valley between Gunnison and Ninemile Reservoirs, and along the eastern margin of the West Hills (plate 13). The areas having Drinking Water Quality ground water cover about 32 percent of the total valley-fill material.

Class 3 - Limited Use ground water: For this class, no TDS values between 3,000 and 10,000 mg/L exist. However, water from the 23 wells completed in the principal aquifer that exceed ground-water quality standards (two wells for arsenic, two wells for lead, one well for copper, and 18 wells for nitrate) is considered Limited Use ground water. Most of these wells could not be mapped as a discrete class 3 area due to their sporadic distribution; however, we map one area with high-nitrate levels north of Moroni (plate 13) as Limited Used ground water based on our interpretation that the water-quality degradation may be areally extensive rather than individual, single-well contaminations (see previous section "Extent of Areas with High Nitrate Concentrations" for interpretation). The area of Limited Use ground water covers about 1.5 percent of the total valley-fill material.

RECOMMENDATIONS TO REDUCE FUTURE WATER-QUALITY DEGRADATION

Introduction

We consider three basic options for controlling the degradation of ground-water quality, principally related to potential sources of nitrate. In Sanpete Valley, these options include: (1) reducing pollution at the source by generating or using less of the substance; (2) implementing best-management practices in agricultural, domestic, industrial, or natural systems to minimize leakage or loss, or to maximize renovation by natural processes; and (3) collecting and treating wastes to prevent pollutants from being discharged into the environment (National Academy of Sciences, 1978). Combining all of these options is likely the most prudent approach.

The most significant nitrate-related environmental impacts are associated with diffuse (nonpoint) sources such as domestic wastewater disposal, agricultural fertilizer application, and feed-lot activities. The options for controlling nitrogen from nonpoint sources range from reduction of problems at the source, such as limiting fertilizer application rates or disbursing farm animals onto pastures and rangeland, to the collection of wastes and subsequent treatment similar to practices used at point sources (National Academy of Sciences, 1978). The benefits of implementing these options must be weighed against economic consequences.

Domestic Wastewater Disposal

Wastewater from septic tank soil-absorption systems contains many constituents that can cause water-quality degradation (table 14). Many constituents discharged into the soil via septic tank soil-absorption systems reach ground water untreated. Hansen, Allen, and Luce, Inc. (1984) estimated that the average Utah household disposes 400 gallons per day (1,500 L/d) of water into the ground; at that wastewater discharge rate, each liter of septic-tank effluent contains 30 to 80 milligrams of nitrate (Hansen, Allen, and Luce, Inc., 1984). For a large family using 400 gallons (1,500 L) of water a day for indoor use, the daily loading of nitrate to ground water would be 45 to 120 grams (1.4-3.6 ounces) per day, or 32 to 82 pounds (15-37 kg) of nitrate per year.

Table 14. *Typical characteristics of wastewater from septic-tank systems (from Hansen, Allen, and Luce, Inc., 1994).*

Parameter	Quantity (mg/L+)
Total Solids	680 - 1000
Volatile Solids	380 - 500
Suspended Solids	200 - 290
Volatile Suspended Solids	150 - 240
BOD(Biological Oxygen Demand)	200 - 290
Chemical Oxygen Demand	680 - 730
Total Nitrogen	35 - 170
Ammonia	6 - 160
Nitrites and Nitrates	<1
Total Phosphorus	18 - 29
Phosphate	6 - 24
Total Coliforms	10^{10} - 10^{12} **MPN/100#mL
Fecal Coliforms	10^{8} - 10^{10} **MPN/100#mL
pH	7.2 - 8.5
Chlorides	86 - 128
Sulfates	23 - 48
Iron	0.26 - 3.0
Sodium	96 - 110
Alkalinity	580 - 775
P-Dichlorobenzene*	0.0039
Toluene*	0.0200
1,1,1-Trichloroethane*	0.0019
Xylene*	0.0028
Ethylbenzene*	0.004
Benzene*	0.005

\+ reported in mg/L except where noted and for pH
* Volatile Organics are the maximum concentrations
** Most probable number

Richardson (1907, p. 32) wrote, "Ill-kept privies and cesspools are nuisances that should not be tolerated in settled communities....Where there are public-water supplies it is desirable that sewers should also be installed..." Sanpete Valley's valley-fill aquifer is now essentially one large public-water supply. We believe it would be prudent to extend and require the use of sanitary sewer systems in all but the most rural areas of the valley. A conventional primary plus secondary sewer treatment facility commonly removes 30 to 40 percent of the nitrogen in raw sewage (National Academy of Sciences, 1978), and systems with tertiary treatment should be even more effective in removing potential pollutants.

Agricultural Fertilizer Applications

Techniques that can be applied to minimize nitrogen losses from croplands include: (1) established practices of efficient agricultural management, (2) innovative applications of agricultural technology, (3) regulations limiting fertilizer applications, and (4) fundamental changes in the patterns of land use and crop production (National Academy of Sciences, 1978). In Sanpete Valley, some of these techniques are more feasible than others; some issues below address this.

In areas of irrigated crops, the flux of nitrate to ground water via leaching and to surface water via return irrigation flows is a function of both the volume of water moving through the soil and the nitrate concentration in the water and soil (National Academy of Sciences, 1978). By increasing water-use efficiency, it may be possible to reduce the total mass of nitrate leaving the root zone and thus becoming unavailable for plant use, although the concentration of nitrate in the smaller volume of infiltrating water may increase. Saffigna and others (1977) demonstrated that a "minimal leaching" approach reduced water drainage by 35 percent, and lowered nitrate losses from 185 to 104 kilograms (407-229 lbs) per hectometer. The costs of installation of sprinkler irrigation systems or lined canals may be partially offset by reduced water consumption (National Academy of Sciences, 1978).

Crop rotations can reduce the amount of fertilizer which needs to be applied. Legume nitrogen fixation can help provide nutrients at shallow depth for the use of other crop types, such as corn, while scavenging residual fertilizers at deeper soil depths, reducing overall leaching of nitrogen (National Academy of Sciences, 1978). Research to increase nitrogen fixation by legumes, mainly through genetic engineering of Rhizobium, could lead to less dependence on chemical fertilizers (National Academy of Sciences, 1978). A reduction of the total area planted through greater crop yields, if not accompanied by an offsetting increase in fertilizer applications, would also lead to a reduction of nitrate reaching ground water (National Academy of Sciences, 1978).

As a rule, nitrate accumulation in agricultural systems occurs when fertilizer inputs exceed amounts that can be efficiently used by crops (National Academy of Sciences, 1978). In the example presented in figure 31, crop yields increased with fertilizer inputs up to about 180 kilograms (400 lbs) per hectometer with little nitrogen being retained in the soil, but at an input of 360 kilograms (800 1bs) per hectometer at least 162 kilograms (350 lbs) of nitrogen was lost from crop use by leaching and/or denitrification. One possible way of minimizing such water-quality degradation would be to restrict fertilizer applications to rates that do not exceed the economic optimum (National Academy of Sciences, 1978). The overall quantity of fertilizer that could be applied under such a scenario could be increased if the fertilizer was applied in smaller amounts, but at a greater frequency. This follows a logical approach of increasing fertilizer efficiency by supplying nitrogen as it is needed, that is, to match the fertilizer applications closely to the nitrogen uptake curve throughout the growing season (Stanford, 1973). Inorganic, slow-release fertilizers having low solubility can also maximize uptake of nitrogen by crops and minimize loss by leaching (National Academy of Sciences, 1978), thus minimizing water-quality degradation from nitrates.

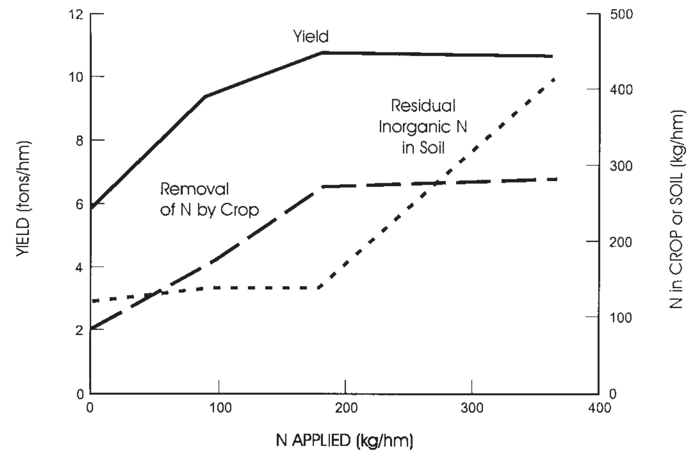


Figure 31. *Yield, removal of nitrogen by crop, and residual nitrogen in soil after harvest at different nitrogen fertilizer application rates (from Natural Academy of Sciences, 1978).*

Feed-Lot Activities

Common options for control of pollution from feed lots include: (1) containment facilities, (2) land spreading of manures, (3) anaerobic or aerobic treatment of collected wastes in lagoons or oxidation ponds, and/or combining these methods (National Academy of Sciences, 1978).

Simple containment facilities for solid manures can be very effective in controlling runoff and accompanying pollution in arid areas, but this option may only be 50 to 80 percent efficient in other, higher precipitation areas because of higher runoff volume (National Academy of Sciences, 1978). The higher cost and lower effectiveness of runoff controls in high-rainfall areas along with zero-discharge regulations will likely facilitate an increase in the development of feed-lot industries in the arid southwest (Viets, 1971). Storage of manure from turkey and cattle operations in Sanpete Valley is common. One method to reduce nitrogen to ground water from these operations is to store manure on impermeable slabs with curbs to contain water and facilities to drain moisture from the slabs without discharging it to the environment. We encourage storing manure at least 100 feet (30 m) away from water wells, which themselves can be direct pathways of pollutants to ground water, especially if they are not prop-

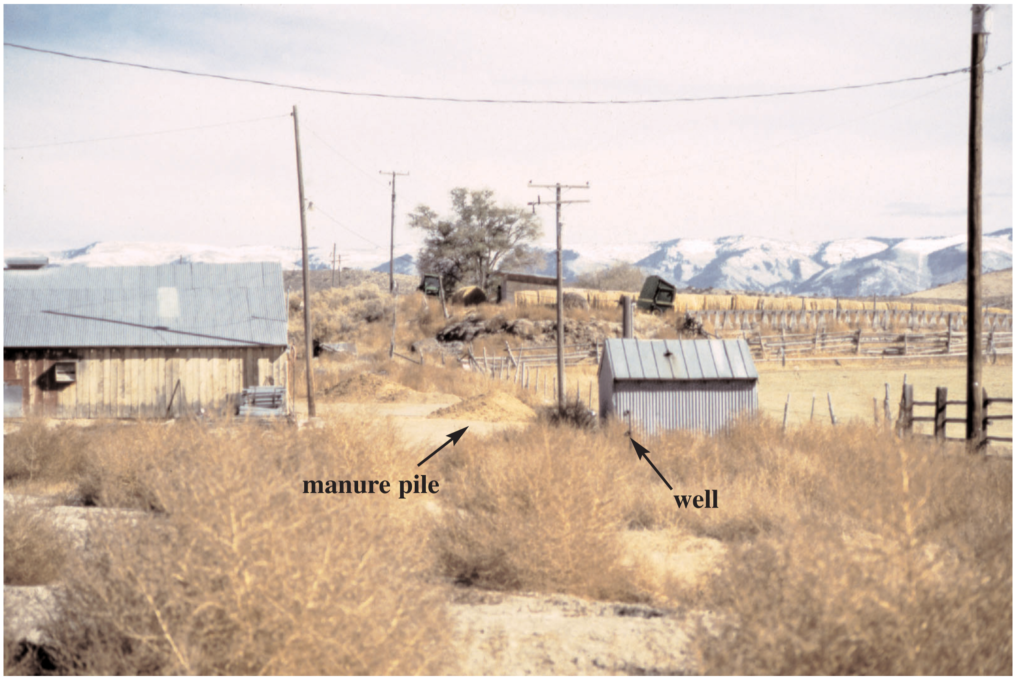


Figure 32. *Example of turkey manure pile near a well having a high nitrate concentration in Sanpete Valley, Sanpete County, Utah.*

erly constructed and maintained. Figure 32 shows a turkey manure pile near one of the high-nitrate wells in Sanpete Valley.

Anaerobic lagoons can create odor problems, and sludge build up is a deterrent to their use; aerobic treatment mitigates the odor problems, but adds to the complexity and expense of treatment (National Academy of Sciences, 1978). Both methods produce concentrated effluents (National Academy of Sciences, 1978); preventing discharge to both surface water and ground water, either via spills or leakage through lagoon liners, will help protect water quality.

Land disposal can be a viable method for handling livestock wastes if manures are applied at rates of nitrogen input equivalent to recommended fertilizer applications, and if they are mixed into the soil to minimize ammonia losses (National Academy of Sciences, 1978). The area required for land spreading of a specific quantity of manure or selection of a specific type of preferred management practice depends on factors such as climate, soil types, terrain, and other site-specific parameters (National Academy of Sciences, 1978).

SUMMARY AND CONCLUSIONS

Protecting ground-water resources is a priority in the Utah State Comprehensive Ground Water Management Plan and the State Nonpoint Source Assessment and Management Plan. High nitrate levels in ground water have been documented locally in Sanpete Valley, where many wells have historically yielded ground water with greater than 40 mg/L nitrate concentration, including a Moroni City well that exceeded the maximum contaminant level of 10 mg/L nitrate concentration and was ultimately taken off line. This study was prompted by this incident and by the concern of potential water-quality degradation in Sanpete Valley.

The objective of our study was to provide local government officials, state agencies, and private water users with: (1) maps showing total-dissolved-solids and nitrate concentrations and ground-water quality classes for the principal valley-fill aquifer, (2) an examination of the relationship of drainage-basin geology and ground-water quality, (3) an identification of all likely sources of nitrate contamination, and (4) an evaluation of transport and fate of nitrate in Sanpete Valley. We analyzed ground water samples from 443 water wells and surface water from two ponds for nutrients. Wells were selected for sampling based on their location and discrete depths of perforated intervals within the valley-fill aquifer to identify a possible correlation between water quality and depth for shallow wells (<100 feet [<30 m]), medium-depth wells (100-200 feet [30-61 m]), and deep wells (>200 feet [61m]). Of the 443 wells, 118 were tested for general chemistry, 107 for dissolved metals, and 49 for organics and pesticides. Utah drinking-water standards were exceeded for lead in two wells, arsenic in two other wells, and copper in another well. Of water wells tested for pesticides, seven wells yielded water having values above the detection limit, but at levels below Utah drinking-water standards.

Total-dissolved-solids concentrations for wells tested for general chemistry range from 234 to 2,752 mg/L. Approximately 66.5 percent of the aquifer by area is classified as class 1A (Pristine), 32 percent by area is classified as class 2 (Drinking Water), and about 1.5 percent by area is classified as class 3 (Limited Use). Elevated levels of total-dissolved-solids concentrations in ground water are largely attributed to proximity to outcrops of the Green River Formation and the Arapien Shale.

Average nitrate concentration for ground water in the valley-fill aquifer is about 3.3 mg/L. Of the water wells analyzed for nitrate, 86.5 percent yielded values less than 5 mg/L, and only three percent exceeded Utah drinking-water standards for nitrate. Most of the high-nitrate wells are less than 150 feet (46 m) deep and/or in primary recharge areas. Simulated reverse particle locations, computed from the results of the modeling, indicate that ground-water flow rates near the contaminated wells range from 7 to 200 feet per year (2-61 m/yr), indicating that contamination sources are likely within a short distance (1.5 miles [2.4 km]) of the high-nitrate wells.

Overall water quality in Sanpete Valley is good. Although a positive correlation exists between current or preexisting animal feed-lot operations and wells yielding high nitrate concentration, we believe no single land-use practice is responsible for the high-nitrate-concentration wells and that multiple nitrogen sources exist, including septic-tank systems, agricultural fertilizer, and animal-waste products. We map one area in northwestern Sanpete Valley having three high-nitrate wells as class 3 (Limited Use) due to persistent high nitrate concentrations, unstable well condition, and consistent land-use practices. Data indicate the remainder of the other high-nitrate wells may be isolated single-well contaminations. However, few or no data points (wells) near these isolated high-nitrate wells preclude a ground-water mixing interpretation. We recommend installing monitoring wells downgradient from the impacted wells in order to make this determination.

To control potential degradation of ground-water quality for wells in Sanpete Valley, we recommend: (1) applying agricultural fertilizer to the surface at rates not exceeding nitrogen uptake by crops, (2) storing feed-lot waste on facilities designed to prevent leakage of contaminants associated with manure to ground water, and (3) avoiding septic-tank system installation in areas where implementation of a public-sewer system is feasible.

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APPENDICES

APPENDIX A

Potential Contaminant Inventory Data for Sanpete Valley (based on data collected in the field for this report by Janae Wallace: site numbers correspond to site numbers on plate 2).

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
1	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizers, manure, nitrates
2	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizers, manure, nitrates
3	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizers, manure, nitrates
4	Junk Yard/Salvage	junk site	metals, solvents, petroleum
5	Mining	quarry	metals, solvents, petroleum
6	Concentration of Animals and/or Feed Lot	elk ranch	fertilizers, manure, nitrates
7	Large Lawn	cemetery	pesticides, fertilizer
8	Storage Tank	gravity driven gas tank	petroleum
9	FCAF*	abandoned animal feeding operation	fertilizers, manure, nitrates
10	Storage Tank	gravity driven gas tank	petroleum
11	Storage Tank	2 gravity driven gas tank, gas pump	petroleum
12	Storage Tank	gravity driven gas tank	petroleum
13	Storage Tank	gravity driven gas tank	petroleum
14	Storage Tank	2 gravity driven gas tank	petroleum
15	Business	beauty salon	metals, solvents
16	FCAF, Junk yard junk yard/salvage	abandoned animal feeding operation, metals, solvents	fertilizers, manure, nitrates,
17	FCAF	corral, abandoned animal feeding operation	fertilizers, manure, nitrates
18	Business	RV dumping	metals, solvents
19	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizers, manure, nitrates
20	Service Station	gas station	metals, petroleum, solvents
21	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
22	Large Lawn	ball park	pesticides, fertilizer
23	Storage Tank	gravity driven gas tank	petroleum
24	Mining	abandoned gravel pit/gravity driven gas tank/ lumber junk	metals, solvents, petroleum
25	Storage Tank	gravity driven gas tank	petroleum
26	Concentration of Animals and/or Feed Lot	barns, animal feeding operation	fertilizers, manure, nitrates
27	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
28	Storage Tank	2 gravity driven gas tank	petroleum
926	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
29	Storage Tank	gravity driven gas tank	petroleum
30	Storage Tank	gravity driven gas tank	petroleum
31	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizers, manure, nitrates
32	Mining	gravel pit	metals, solvents, petroleum
33	Service Station	service station	solvents, petroleum
34	Large Lawn	cemetery	pesticides, fertilizer
35	Large Lawn	ball park	pesticides, fertilizer
36	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizers, manure, nitrates
37	Concentration of Animals and/or Feed Lot	animal feeding operation, large scale	fertilizers, manure, nitrates
38	Service Station	service station	petroleum, solvents
39	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
40	Storage Tank	gravity driven gas tank	petroleum
41	Storage Tank	gravity driven gas tank	petroleum
42	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
43	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
44	Concentration of Animals and/or Feed Lot	dairy farm	fertilizer, manure, nitrates
45	Service Station	car repair	metals, solvents, petroleum
46	Concentration of Animals and/or Feed Lot	ostrich farm	fertilizers, manure, nitrates
47	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
48	Storage Tank	gravity driven gas tank	petroleum
49	FCAF	abandoned poultry	fertilizers, manure, nitrates
50	FCAF	abandoned animal feeding operation	fertilizers, manure, nitrates
51	Large Lawn	golf course	pesticides, fertilizer
52	Business	taxidermy, kennels	manure, nitrates, metals, solvents
53	FCAF	abandoned swine farm	fertilizers, manure, nitrates
54	Concentration of Animals and/or Feed Lot	corrals	fertilizers, manure, nitrates
55	Concentration of Animals and/or Feed Lot	corrals	fertilizers, manure, nitrates
56	Mining	quarries	metals, solvents, petroleum
57	Mining	quarries	metals, solvents, petroleum
58	Mining	quarries	metals, solvents, petroleum
59	Mining	quarries	metals, solvents, petroleum
60	Mining	quarries	metals, solvents, petroleum
61	Mining	gravel pit	metals, solvents, petroleum
194	Mining	quarries	metals, solvents, petroleum
925	Mining	gravel pit	metals, solvents, petroleum
62	Concentration of Animals and/or Feed Lot	turkey operation	fertilizers, manure, nitrates
63	Concentration of Animals and/or Feed Lot	turkey operation	fertilizers, manure, nitrates
64	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizers, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
65	FCAF	animal feeding operation, abandoned turkey farm	fertilizers, manure, nitrates
66	Junk Yard/Salvage	small junk yard/salvage	metals, solvents, petroleum
67	FCAF	sheds, abandoned poultry operation	fertilizers, manure, nitrates
68	Government	county road department	metals, solvents, petroleum
69	Industry	auto body & glass shop	metals, solvents, petroleum
70	Industry	transformer station	Polychlorinated Biphenyl (PCB)
71	Business	cabinets mill	metals, solvents
72	Storage Tank	gravity driven gas tank	petroleum
73	Business	lumber dealer	metals, solvents, petroleum
74	Waste Disposal	2 sewage lagoon, drained and filled	metals, solvents, nitrates
75	FCAF	abandoned turkey sheds	fertilizers, manure, nitrates
76	Junk Yard/Salvage	farm storage site	fertilizers, manure, nitrates
77	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
78	Concentration of Animals and/or Feed Lot	poultry operation	fertilizer, manure, nitrates
79	Storage Tank	gas pump	petroleum
80	Large Lawn	park	pesticides, fertilizer
81	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
82	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
83	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
84	Large Lawn	ball park	pesticides, fertilizer
85	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
86	Business	hardware store	metals, solvents
87	Government	county fairgrounds	fertilizer, manure, petroleum,solvents
88	Service Station	service station	metals, solvents, petroleum
89	Business	auto body shop	metals, solvents, petroleum
90	Business	auto care center	metals, solvents, petroleum
91	Government	fire station	metals, solvents, petroleum
92	Medical	health care facility	metals, solvents
93	Service Station	service station	metals, solvents, petroleum
94	Business	auto parts store	metals, solvents, petroleum
95	Business	beauty salon	metals, solvents
96	Business	hardware store	metals, solvents
97	Medical	dentistry	metals, solvents
98	Business	storage units	metals, solvents, petroleum
99	Business	beauty salon	metals, solvents
100	Government	government	metals, solvents, petroleum
101	Government	armory	metals, solvents, petroleum
102	Mining, service station	abandoned service station, sand & gravel	metals, solvents, petroleum
103	Medical	chiropractor	metals, solvents
104	FCAF	abandoned coop, corral	fertilizer, manure, nitrates
105	Storage Tank	gravity driven gas tank	petroleum
106	Mining	quarries	metals, solvents, petroleum
107	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
108	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
109	Business	storage units	metals, solvents, petroleum
110	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
111	Business	rose distributor	metals, solvents, pesticides
112	Business	Laundromat	metals, solvents
113	Industry	construction company	metals, solvents, petroleum
114	Service Station	carwash	petroleum, metals, solvents
115	Business	funeral home	metals, solvents
116	Business	mechanic	metals, solvents, petroleum
117	Business	storage units	metals, solvents, petroleum
118	Business	abandoned lumber company, shop and swap	metals, solvents, petroleum
119	Industry	mini power station	PCB
120	Storage Tank	gravity driven gas tank	petroleum
121	FCAF	abandoned chicken or turkey coop	fertilizer, manure, nitrates
122	Mining	gravel pit	metals, solvents, petroleum
123	Storage Tank	gravity driven gas tank	petroleum
124	Service Station	petroleum storage tanks	metals, solvents, petroleum
125	FCAF	abandoned chicken coop, corrals	fertilizer, manure, nitrates
126	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
127	Junk Yard/Salvage	junkyard/ personal dump	fertilizer, manure, petroleum, solvents
128	Large Lawn	cemetery	pesticides, fertilizer
129	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
130	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
131	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizer, manure, nitrates
132	Concentration of Animals and/or Feed Lot	dairy farm, animal feeding operation	fertilizer, manure, nitrates
133	Concentration of Animals and/or Feed Lot	dairy farm, animal feeding operation	fertilizer, manure, nitrates
134	Storage Tank	gravity driven gas tank	petroleum
135	Concentration of Animals and/or Feed Lot	corrals	fertilizer, manure, nitrates
136	FCAF	abandoned animal feeding operation, corral	fertilizer, manure, nitrates
137	Waste Disposal	sewage lagoon	metals, solvents, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
138	Concentration of Animals and/or Feed Lot	turkey operation, small	fertilizer, manure, nitrates
139	Concentration of Animals and/or Feed Lot	corrals	fertilizer, manure, nitrates
140	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizer, manure, nitrates
141	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizer, manure, nitrates
142	Storage Tank	gravity driven gas tank	petroleum
143	Concentration of Animals and/or Feed Lot	large scale animal feeding operation	fertilizer, manure, nitrates
144	Storage Tank	4 gravity driven gas tank	petroleum
145	Concentration of Animals and/or Feed Lot	sheep operation, corral	fertilizer, manure, nitrates
146	Storage Tank	2 gravity driven gas tank	petroleum
147	FCAF	abandoned corral	fertilizer, manure, petroleum, solvents
148	Storage Tank	gravity driven gas tank	petroleum
149	FCAF	abandoned dairy farm	fertilizer, manure, nitrates
150	Mining	gravel pit	metals, solvents, petroleum
151	Concentration of Animals and/or Feed Lot	corrals	fertilizer, manure, nitrates
152	Concentration of Animals and/or Feed Lot	corrals	fertilizer, manure, nitrates
153	Mining	gravel pit	metals, solvents, petroleum
154	Mining	gravel pit	metals, solvents, petroleum
155	Concentration of Animals and/or Feed Lot	animal feeding operation, large scale	fertilizer, manure, nitrates
156	Concentration of Animals and/or Feed Lot	turkey operation, large	fertilizer, manure, nitrates
157	Concentration of Animals and/or Feed Lot	turkey sheds	fertilizer, manure, nitrates
158	Concentration of Animals and/or Feed Lot	turkey sheds	fertilizer, manure, nitrates
159	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
160	Concentration of Animals and/or Feed Lot	turkey operation, large	fertilizer, manure, nitrates
161	FCAF	abandoned turkey sheds	fertilizer, manure, nitrates
162	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
163	Storage Tank	gravity driven gas tank	petroleum
164	Industry	airport	metals, solvents, petroleum
165	FCAF	abandoned corral	fertilizer, manure, nitrates
166	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizer, manure, nitrates
167	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizer, manure, nitrates
168	Concentration of Animals and/or Feed Lot	sheep operation	fertilizer, manure, nitrates
169	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
170	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
171	FCAF	abandoned small scale animal feeding operation	fertilizer, manure, nitrates
172	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
173	Junk Yard/Salvage	recycling business	metals, solvents, petroleum
174	Business	tractor farm equipment	metals, solvents, petroleum
175	Business, Large Lawn	truck/trailer renting, nursery	fertilizer, metals, petroleum, solvents, pesticides
176	Business	automotive repair/tire center	metals, solvents, petroleum
177	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
178	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
179	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizer, manure, nitrates
180	Industry	power sub station	PCB
181	Waste Disposal	sewage lagoon	solvents, metals, nitrates
182	Concentration of Animals and/or Feed Lot	corrals	fertilizer, manure, nitrates
183	Storage Tank	2 gravity driven gas tanks	petroleum
184	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
185	Industry	auto meter products	metals, solvents, petroleum
186	Concentration of Animals and/or Feed Lot	turkey operation, small	fertilizer, manure, nitrates
187	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
188	Business	auto tire and batteries	metals, solvents, petroleum
189	Business	storage units	metals, solvents, petroleum
190	Industry	animal feed	metals, solvents, fertilizer, nitrates
191	Business	construction company	metals, solvents, petroleum
192	Industry	power sub station	PCB
193	Business	construction company	metals, solvents, petroleum
195	Storage Tank	2 gravity driven gas tank	petroleum
196	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizer, manure, nitrates
197	Waste Disposal	sewage lagoon	metals, solvents, nitrates
198	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
199	Storage Tank	gravity driven gas tank	petroleum
200	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
201	Storage Tank	gravity driven gas tank	petroleum
202	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
203	Large Lawn	cemetery	pesticides, fertilizer
204	Industry	power sub station	PCB
205	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
206	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
207	Storage Tank	2 gravity driven gas tank	petroleum
208	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
209	Storage Tank	gravity driven gas tank	petroleum

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
210	Mining	inactive gravel pit	metals, solvents, petroleum
211	Mining	inactive gravel pit	metals, solvents, petroleum
212	Storage Tank	gravity driven gas tank	petroleum
213	Concentration of Animals and/or Feed Lot	corral, sheep, horses	fertilizer, manure, nitrates
214	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
215	FCAF	abandoned corral	fertilizer, manure, nitrates
216	FCAF	abandoned corral	fertilizer, manure, nitrates
217	Mining	gravel pit	metals, solvents, petroleum
218	Mining	gravel pit	metals, solvents, petroleum
219	Industry	power sub station	PCB
220	Storage Tank	small gravity driven gas tank	petroleum
221	Government	government, tools	metals, solvents, petroleum
222	Industry	small power sub station	PCB
223	FCAF	abandoned corral	fertilizer, manure, nitrates
224	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
225	Large Lawn	ball park	pesticides, fertilizer
226	Storage Tank	gravity driven gas tank	petroleum
227	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
228	Business	construction company	metals, solvents, petroleum
229	Large Lawn	athletic field	pesticides, fertilizer
230	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
231	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
232	Storage Tank	gravity driven gas tank	petroleum
233	Concentration of Animals and/or Feed Lot	temporary housing for animals	fertilizer, manure, nitrates
234	Concentration of Animals and/or Feed Lot	turkey operation, sheds	fertilizer, manure, nitrates
235	Concentration of Animals and/or Feed Lot	sheep operation	fertilizer, manure, nitrates
236	Concentration of Animals and/or Feed Lot	turkey operation (large)	fertilizer, manure, nitrates
237	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
238	Concentration of Animals and/or Feed Lot	turkey operation, sheds	fertilizer, manure, nitrates
239	Storage Tank	gravity driven gas tank	petroleum
240	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
241	FCAF	abandoned corral	fertilizer, manure, nitrates
242	FCAF	abandoned slaughter house	fertilizer, manure, metals, solvents
243	Service Station	service station	metals, solvents, petroleum
244	Service Station	service station	metals, solvents, petroleum
245	Business	meat distributor	metals, solvents
246	Junk Yard/Salvage	recycling center	metals, solvents, petroleum
247	FCAF	abandoned corral	fertilizer, manure, nitrates
248	Storage Tank	gravity driven gas tank	petroleum
249	Concentration of Animals and/or Feed Lot	elk ranch	fertilizer, manure, nitrates
250	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
251	Business	auto parts store	metals, solvents, petroleum
252	Business	fertilizer, handy man business	fertilizer, petroleum, solvents
253	Medical	pharmacy	metals, solvents
254	Large Lawn	large lawn	pesticides, fertilizer
255	Business	auto sales	metals, solvents, petroleum
256	Business	lawn care and pest control	pesticides, fertilizer
257	Service Station	carwash	metals, solvents, petroleum
258	Medical	veterinary	metals, manure, solvents
259	Business	auto repair	metals, solvents, petroleum
260	Business	storage units	metals, solvents, petroleum
261	Business	Laundromat	metals, solvents
262	Medical	dentistry	metals, solvents
263	Medical	eye care facility	metals, solvents
264	Concentration of Animals and/or Feed Lot	small scale animal feeding operation	fertilizer, manure, nitrates
265	Concentration of Animals and/or Feed Lot	dairy farm, animal feeding operation	fertilizer, manure, nitrates
266	Concentration of Animals and/or Feed Lot	turkey operation, sheds	fertilizer, manure, nitrates
267	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
268	Storage Tank	gravity driven gas tank	petroleum
269	Storage Tank	gravity driven gas tank	petroleum
270	FCAF	abandoned corral	fertilizer, manure, nitrates
271	Storage Tank	gravity driven gas tank	petroleum
272	Storage Tank	gravity driven gas tank	petroleum
273	Business	personal business	metals, solvents
274	Service Station	service station	metals, solvents, petroleum
275	Business	beauty salon	metals, solvents
276	Medical	dentistry	metals, solvents
277	Business	copy center	metals, solvents
278	Concentration of Animals and/or Feed Lot	turkey sheds	fertilizer, manure, nitrates
279	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
280	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
281	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
282	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
283	Storage Tank	gravity driven gas tank	petroleum
284	Business	dog grooming	metals, solvents
285	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
286	Business	beauty salon, upholstery	metals, solvents
287	Business	tire distributor	metals, solvents, petroleum
288	Service Station	service station	metals, solvents, petroleum
289	Storage Tank, Concentration of Animals	gravity driven gas tank, corral	petroleum, manure, nitrates
290	FCAF	abandoned coop	fertilizer, manure, nitrates
291	Industry	power sub station	PCB
292	Storage Tank, Concentration of Animals and/or Feed Lot	2 gravity driven gas tank, corral	petroleum, manure, nitrates
293	Medical	veterinary	metals, manure, solvents
294	Storage Tank, Concentration of Animals and/or Feed Lot	3 gravity driven gas tank, corral	petroleum, manure, nitrates
295	Government	City Offices; garage	metals, solvents, petroleum
296	Business	honey distributer	metals, solvents
297	Storage Tank	gravity driven gas tank	petroleum
298	FCAF	abandoned poultry	fertilizer, manure, nitrates
299	Large Lawn	ball park	pesticides, fertilizer
300	FCAF	abandoned farm operation	fertilizer, manure, nitrates
301	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
302	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
303	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
304	Large Lawn	ball park	pesticides, fertilizer
305	Junk Yard/Salvage, Government	car junk yard/salvage, army vehicles	metals, solvents, petroleum
306	Storage Tank	gravity driven gas tank	petroleum
307	Concentration of Animals and/or Feed Lot	coop, sheep	fertilizer, manure, nitrates
308	Storage Tank	gravity driven gas tank	petroleum
309	Storage Tank	gravity driven gas tank	petroleum
310	FCAF	abandoned coop	fertilizer, manure, nitrates
311	Storage Tank	gravity driven gas tank	petroleum
312	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
313	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
314	Storage Tank	gravity driven gas tank	petroleum
315	Concentration of Animals and/or Feed Lot	horses	fertilizer, manure, nitrates
316	Storage Tank	gravity driven gas tank	petroleum
317	Concentration of Animals and/or Feed Lot	corral, sheep	fertilizer, manure, nitrates
318	Storage Tank	gravity driven gas tank	petroleum
319	Concentration of Animals and/or Feed Lot	animal feeding operation	fertilizer, manure, nitrates
320	Large Lawn	cemetery	pesticides, fertilizer
321	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
322	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
323	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
324	FCAF	abandoned corral	fertilizer, manure, nitrates
325	Concentration of Animals and/or Feed Lot	confined farm animals	fertilizer, manure, nitrates
326	Concentration of Animals and/or Feed Lot	concentration of animals	fertilizer, manure, nitrates
327	Concentration of Animals and/or Feed Lot	turkey operation, sheds	fertilizer, manure, nitrates
328	Storage Tank	2 gravity driven gas tank	petroleum
329	Mining	quarries	metals, solvents, petroleum
330	Mining	quarries	metals, solvents, petroleum
331	Mining	quarries	metals, solvents, petroleum
332	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
333	Mining	borrow pit	metals, solvents, petroleum
334	Mining	borrow pit	metals, solvents, petroleum
335	Large Lawn	cemetery	pesticides, fertilizer
336	Storage Tank	2 gravity driven gas tank	petroleum
337	Concentration of Animals and/or Feed Lot	turkeys	fertilizer, manure, nitrates
338	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
339	Concentration of Animals and/or Feed Lot	corral, sheep	fertilizer, manure, nitrates
340	Concentration of Animals and/or Feed Lot	sheds-turkey	fertilizer, manure, nitrates
341	Storage Tank	gravity driven gas tank	petroleum
342	Junk Yard/Salvage, Storage Tank	junk yard/salvage, gravity driven gas tank	metals, solvents, petroleum
343	FCAF	abandoned corral	fertilizer, manure, nitrates
344	FCAF	abandoned corral	fertilizer, manure, nitrates
345	FCAF	abandoned corral	fertilizer, manure, nitrates
346	Storage Tank	gravity driven gas tank	petroleum
347	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
348	Storage Tank	gravity driven gas tank	petroleum
349	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
350	Storage Tank	gravity driven gas tank	petroleum
351	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
352	Mining	inactive gravel pit	petroleum
353	Mining	borrow pit	metals, solvents, petroleum
354	Mining	inactive borrow pit	metals, solvents, petroleum

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
355	Mining	inactive borrow pit	metals, solvents, petroleum
356	Mining	inactive borrow pit	metals, solvents, petroleum
357	FCAF	abandoned corral	fertilizer, manure, nitrates
358	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
359	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
360	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
361	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
362	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
363	Storage Tank	gravity driven gas tank	fertilizer, manure, petroleum, solvents
364	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
365	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
366	Mining	inactive Borrow Pit	metals, solvents, petroleum
367	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
368	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
369	FCAF	abandoned corral	fertilizer, manure, petroleum, solvents
370	Storage Tank	gravity driven gas tank	petroleum
371	Business	auto wrecking	metals, solvents, petroleum
372	Concentration of Animals and/or Feed Lot	corral, swine, cows	fertilizer, manure, nitrates
373	Business	repair shop	metals, solvents, petroleum
374	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
375	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
376	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
377	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
378	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
379	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
380	Mining	borrow pit	metals, solvents, petroleum
381	Concentration of Animals and/or Feed Lot	dairy farm	fertilizer, manure, nitrates
382	Concentration of Animals and/or Feed Lot	dairy farm, animal feeding operation	fertilizer, manure, nitrates
383	Large Lawn	cemetery	pesticides, fertilizer
384	FCAF	abandoned corral	fertilizer, manure, nitrates
385	FCAF	abandoned corral	fertilizer, manure, nitrates
386	Large Lawn	cemetery	pesticides, fertilizer
387	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
388	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
389	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
390	Storage Tank	2 gravity driven gas tank	petroleum
391	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
392	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
393	FCAF	abandoned corral	fertilizer, manure, nitrates
394	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
395	Storage Tank	gravity driven gas tank	petroleum
396	Concentration of Animals and/or Feed Lot	turkey operation sheds	fertilizer, manure, nitrates
397	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
398	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
399	Storage Tank	gravity driven gas tank	petroleum
400	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
401	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
402	Mining	borrow pit	metals, solvents, petroleum
403	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
404	FCAF	abandoned corral	fertilizer, manure, nitrates
405	Storage Tank	gravity driven gas tank	petroleum
406	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
407	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
408	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
409	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
410	Mining	borrow pit	metals, solvents, petroleum
411	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
412	FCAF	abandoned corral	fertilizer, manure, nitrates
413	FCAF	abandoned corral	fertilizer, manure, nitrates
414	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
415	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
416	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
417	FCAF	abandoned corral	fertilizer, manure, nitrates
418	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
419	Storage Tank	gravity driven gas tank	petroleum
420	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
421	FCAF	abandoned corral	fertilizer, manure, nitrates
422	Storage Tank	gravity driven gas tank	petroleum
423	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
424	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
425	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
426	Business	mulch company	fertilizer, manure, petroleum, solvents

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
427	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
428	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
429	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
430	Waste Disposal	sewage lagoon	metals, solvents, nitrates
431	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
432	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
433	Mining	gravel pit	metals, solvents, petroleum
434	Mining	gravel pit	metals, solvents, petroleum
435	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
436	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
437	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
438	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
439	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
440	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
441	Concentration of Animals and/or Feed Lot	corral, farm	fertilizer, manure, nitrates
442	FCAF	abandoned corral	fertilizer, manure, nitrates
443	FCAF	abandoned corral	fertilizer, manure, nitrates
444	Mining	gravel pit	metals, solvents, petroleum
445	Mining	gravel pit	metals, solvents, petroleum
446	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
447	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
448	Storage Tank	gravity driven gas tank	petroleum
449	Storage Tank	2 gravity driven gas tank	petroleum
450	Mining	gravel pit	petroleum
451	Large Lawn	cemetery	pesticides, fertilizer
452	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
453	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
454	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
455	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
456	Storage Tank	gravity driven gas tank	petroleum
457	Storage Tank	2 gravity driven gas tank	petroleum
458	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
459	Storage Tank	2 gravity driven gas tank	petroleum
460	Storage Tank	gravity driven gas tank	petroleum
461	Storage Tank	gravity driven gas tank	petroleum
462	Storage Tank	gravity driven gas tank	petroleum
463	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
464	Business	abandoned auto body shop	metals, solvents, petroleum
465	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
466	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
467	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
468	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
469	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
470	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
471	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
472	Storage Tank	gravity driven gas tank	metals, solvents, petroleum
473	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
474	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
475	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
476	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
477	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
478	Storage Tank	gravity driven gas tank	petroleum
479	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
480	Storage Tank	gravity driven gas tank	petroleum
481	Mining	abandoned gravel pit	metals, solvents, petroleum
482	Large Lawn	cemetery	fertilizer, manure, nitrates
483	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
484	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
485	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
486	Storage Tank	gravity driven gas tank	petroleum
487	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
488	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
489	Storage Tank	gravity driven gas tank	petroleum
490	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
491	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
492	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
493	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
494	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
495	FCAF	abandoned corral	fertilizer, manure, nitrates
496	FCAF	abandoned corral	fertilizer, manure, nitrates
497	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
498	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
499	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
500	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
501	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
502	Mining	gravel pit	metals, solvents, petroleum
503	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
504	Mining	gravel pit	metals, solvents, petroleum
505	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
506	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
507	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
508	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
509	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
510	Storage Tank	gravity driven gas tank	petroleum
511	FCAF	abandoned dairy farm	fertilizer, manure, nitrates
512	Storage Tank	gravity driven gas tank	petroleum
513	Storage Tank	gravity driven gas tank	petroleum
514	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
515	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
516	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
517	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
518	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
519	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
520	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
521	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
522	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
523	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
524	Mining	gravel pit	metals, solvents, petroleum
525	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
526	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
527	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
528	Storage Tank	gravity driven gas tank	petroleum
529	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
530	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
531	FCAF	abandoned corral	fertilizer, manure, nitrates
532	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
533	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
534	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
535	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
536	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
537	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
538	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
539	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
540	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
541	Storage Tank	gravity driven gas tank	petroleum
542	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
543	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
544	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
545	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
546	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
547	Concentration of Animals and/or Feed Lot	cows/ corral	fertilizer, manure, nitrates
548	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
549	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
550	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
551	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
552	Storage Tank	abandoned gas station	metals, solvents, petroleum
553	Business	construction company	metals, solvents, petroleum
554	FCAF	abandoned dairy farm, turkey operation	fertilizer, manure, nitrates
555	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
556	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
557	Concentration of Animals and/or Feed Lot	sheds	fertilizer, manure, nitrates
558	Concentration of Animals and/or Feed Lot	sheds	fertilizer, manure, nitrates
559	Storage Tank	gravity driven gas tank	petroleum
560	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
561	FCAF	abandoned corral	fertilizer, manure, nitrates
562	Large Lawn	ball park, school	pesticides, fertilizer
563	Storage Tank	gravity driven gas tank	petroleum\
564	Large Lawn	cemetery	pesticides, fertilizer
565	Mining	gravel pit	petroleum
566	FCAF	abandoned corral	fertilizer, manure, nitrates
567	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
568	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
569	Industry	power sub station	PCB
570	Mining	gravel pit	petroleum
571	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
572	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
573	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
574	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
575	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
576	Storage Tank	gravity driven gas tank	petroleum
577	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
578	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
579	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
580	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
581	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
582	Storage Tank	gravity driven gas tank	petroleum
583	Storage Tank	gravity driven gas tank	petroleum
584	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
585	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
586	Concentration of Animals and/or Feed Lot	sheep	fertilizer, manure, nitrates
587	Concentration of Animals and/or Feed Lot	turkey operation, sheep	fertilizer, manure, nitrates
588	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
589	Storage Tank	gravity driven gas tank	petroleum
590	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
591	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
592	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
593	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
594	Waste Disposal	sewage lagoon	metals, solvents, nitrates
595	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
596	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
597	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
598	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
599	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
600	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
601	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
602	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
603	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
604	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
605	FCAF	abandoned corral	fertilizer, manure, nitrates
606	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
607	Business	barber shop	metals, solvents
608	FCAF	abandoned corral	fertilizer, manure, nitrates
609	Business	auto body shop	metals, solvents, petroleum
610	Storage Tank	gas station	metals, solvents, petroleum
611	Large Lawn	park	pesticides, fertilizer
612	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
613	Concentration of Animals and/or Feed Lot	sheep	fertilizer, manure, nitrates
614	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
615	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
616	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
617	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
618	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
619	FCAF	abandoned poultry operation	fertilizer, manure, nitrates
620	FCAF	abandoned poultry operation	fertilizer, manure, nitrates
621	FCAF	abandoned poultry operation	fertilizer, manure, nitrates
622	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
623	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
624	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
625	Storage Tank	gravity driven gas tank	petroleum
626	Large Lawn	ball park	pesticides, fertilizer
627	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
628	Large Lawn	ball park	pesticides, fertilizer
629	Government	fire station	metals, solvents, petroleum
630	Business	auto parts store	metals, solvents, petroleum
631	Service Station	carwash	metals, solvents, petroleum
632	Service Station	gas station	metals, solvents, petroleum
633	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
634	Concentration of Animals and/or Feed Lot	chicken coop	fertilizer, manure, nitrates
635	Business	personal business	metals, solvents
636	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
637	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
638	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
639	Business	automotive repairs	metals, solvents, petroleum
640	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
641	Concentration of Animals and/or Feed Lot	horse race track	fertilizer, manure, nitrates
927	Large Lawn	large lawn	pesticides, fertilizer
642	Medical	dentistry	metals, solvents
643	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
644	Business	garage	metals, solvents, petroleum
645	Industry	power sub station	PCB
646	Large Lawn	large lawn	pesticides, fertilizer

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
647	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
648	Junk Yard/Salvage	personal junk yard	metals, solvents, petroleum
928	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
649	Industry	turkey plant processing	fertilizer, manure, petroleum, solvents
650	Waste Disposal	sewage lagoon	metals, solvents, nitrates
651	FCAF	abandoned corral	fertilizer, manure, nitrates
652	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
929	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
653	Industry	farm feed and hatchery	fertilizer, manure, petroleum, solvents
930	Storage Tank	gravity driven gas tank	petroleum
654	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
931	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
655	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
932	FCAF	sheep, abandoned corral	fertilizer, manure, nitrates
656	Industry	steel company	metals, solvents, petroleum
933	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
657	Storage Tank	2 gravity driven gas tank	petroleum
934	Service Station	gas station for farm feed store	fertilizer, manure, petroleum, solvents
658	Concentration of Animals and/or Feed Lot	cows	fertilizer, manure, nitrates
935	Storage Tank	gravity driven gas tank	petroleum
659	Business	lumber	metals, solvents, petroleum
936	FCAF	abandoned corral	fertilizer, manure, nitrates
660	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
937	Mining	gravel pit	metals, solvents, petroleum
661	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
938	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
662	Concentration of Animals and/or Feed Lot	cows	fertilizer, manure, nitrates
663	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
664	Storage Tank	gravity driven gas tank	petroleum
665	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
666	FCAF	abandoned corral	fertilizer, manure, nitrates
667	Concentration of Animals and/or Feed Lot	sheep	fertilizer, manure, nitrates
668	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
669	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
670	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
671	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
672	Business	farmer co-op coal	metals, solvents, petroleum
673	Business	auto & body shop	fertilizer, manure, nitrates
674	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
675	Mining	gravel pit	petroleum, metals, solvents
676	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
677	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
678	FCAF	abandoned corral	fertilizer, manure, nitrates
679	FCAF	abandoned corral	fertilizer, manure, nitrates
680	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
681	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
682	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
683	Storage Tank	gravity driven gas tank	petroleum
684	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
685	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
686	Industry	airport	metals, solvents, petroleum
687	Storage Tank	3 gravity driven gas tanks	petroleum
688	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
689	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
690	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
691	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
692	Storage Tank	gravity driven gas tank	petroleum
693	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
694	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
695	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
696	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
697	Waste Disposal	sewage lagoon	metals, solvents, nitrate
698	Government	Government (defense unit)	metals, solvents, petroleum
699	Business	carpet store	metals, solvents
700	Business	small business	metals, solvents, petroleum
701	Large Lawn	cemetery	pesticides, fertilizer
702	Business	sheet metal, air conditioning	metals, solvents, petroleum
703	Business	automotive glass store	metals, solvents, petroleum
704	Service Station	gas station	metals, solvents, petroleum
705	Industry	power sub station	PCB
706	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
707	Junk Yard/Salvage	abandoned furniture, junk yard/salvage	metals, solvents, petroleum
708	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
709	Business	storage sheds	fertilizer, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
710	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
711	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
712	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
713	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
714	Industry	petroleum oil products	metals, solvents, petroleum
715	Business	auto repair	metals, solvents, petroleum
716	Industry	petroleum company	metals, solvents, petroleum
717	Government	Government, transportation	metals, solvents, petroleum
718	Business	tire company	metals, solvents, petroleum
719	Business	auto parts store	metals, solvents, petroleum
720	Business	craft store	metals, solvents, petroleum
721	Business	hair salon	metals, solvents
722	Business	boot repair, hardware, plumbing	metals, solvents
723	Service Station	gas station	metals, solvents, petroleum
724	Service Station	gas station	metals, solvents, petroleum
725	Business	Laundromat	metals, solvents
726	Large Lawn	ball park	pesticides, fertilizer
727	Business	dog kennels	metals, solvents
728	FCAF	abandoned corral	fertilizer, manure, nitrates
729	Storage Tank	gravity driven gas tank	petroleum
730	Business	construction company	metals, solvents, petroleum
939	Large Lawn	large lawn	pesticides, fertilizer
731	Business	recreation equipment dealership	metals, solvents, petroleum
732	Business	sheet metal supply	metals, solvents
733	Business	auto parts store	metals, solvents, petroleum
734	Service Station	gas station	metals, solvents, petroleum
735	Junk Yard/Salvage	junk yard/salvage	metals, solvents, petroleum
736	FCAF	abandoned corral	fertilizer, manure, nitrates
737	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
738	Industry	gravel company	petroleum
739	Business	woodcraft shop	metals, solvents
740	Storage Tank	gravity driven gas tank	petroleum
741	Business	trailers/rentals	metals, solvents, petroleum
742	Business	garage auto service	metals, solvents, petroleum
743	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
744	Large Lawn	nursery	pesticides, fertilizer
745	Business	nail salon	metals, solvents
746	Storage Tank	gravity driven gas tank	petroleum
747	Business	hair salon	metals, solvents
748	Business	school bus garage	metals, solvents, petroleum
749	Large Lawn	football field	pesticides, fertilizer
750	Storage Tank	gravity driven gas tank	petroleum
751	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
752	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
753	FCAF	abandoned sheds	fertilizer, manure, nitrates
754	Business	upholstery	metals, solvents
755	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
756	Government	Government	petroleum
757	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
758	Business	auto repair	metals, solvents, petroleum
759	Business	impound service	metals, solvents, petroleum
760	FCAF	abandoned turkey operation	fertilizer, manure, nitrates
761	Government	transportation gravel piles	metals, solvents, petroleum
762	Storage Tank	gravity driven gas tank	petroleum
763	Business	auto shop	metals, solvents, petroleum
764	Concentration of Animals and/or Feed Lot	sheep operation	fertilizer, manure, nitrates
765	Mining	gravel pit	metals, solvents, petroleum
766	Mining	gravel pit	metals, solvents, petroleum
767	Mining	gravel pit	metals, solvents, petroleum
768	Mining	gravel pit	metals, solvents, petroleum
769	Mining	gravel pit	metals, solvents, petroleum
770	Mining	gravel pit	metals, solvents, petroleum
771	FCAF	abandoned corral	fertilizer, manure, nitrates
772	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
773	Storage Tank	gravity driven gas tank	petroleum
774	FCAF	abandoned corral	fertilizer, manure, nitrates
775	FCAF	abandoned corral	fertilizer, manure, nitrates
776	Concentration of Animals and/or Feed Lot	sheep operation	fertilizer, manure, nitrates
777	Storage Tank	gravity driven gas tank	petroleum
778	Storage Tank	gravity driven gas tank	petroleum
779	FCAF, Storage Tank	abandoned dairy farm, gravity driven gas tank	fertilizer, manure, petroleum, solvents
780	FCAF	abandoned corral	fertilizer, manure, nitrates
781	Business	tire and auto	metals, solvents, petroleum
782	Concentration of Animals and/or Feed Lot	rodeo grounds	fertilizer, manure, petroleum, solvents

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
783	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
784	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
785	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
786	FCAF	abandoned dairy farm	fertilizer, manure, nitrates
787	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
788	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
789	Junk Yard/Salvage	car scrap salvage	metals, solvents, petroleum
790	Storage Tank, Junk Yard	2 gravity driven gas tank, junk yard/salvage	metals, solvents, petroleum
791	Industry	concrete plant	metals, solvents
792	Business	concrete store	metals, solvents
793	Business	storage units	metals, solvents, petroleum
794	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
795	Mining	gravel pit	metals, solvents, petroleum
796	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
797	Storage Tank, Junk Yard	gravity driven gas tank	petroleum
798	Concentration of Animals and/or Feed Lot	dairy farm, swine	fertilizer, manure, nitrates
799	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
800	Business	construction company	metals, solvents, petroleum
801	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
802	Storage Tank, Junk Yard	gravity driven gas tank	petroleum
803	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
804	Concentration of Animals and/or Feed Lot	sheep sheds	fertilizer, manure, nitrates
805	Business	diesel supply	metals, solvents, petroleum
806	Business	garage sheds	metals, solvents, petroleum
807	Concentration of Animals and/or Feed Lot	shed	fertilizer, manure, nitrates
808	Medical	dentistry	metals, solvents, petroleum
809	Medical	health care facility	metals, solvents, petroleum
810	Concentration of Animals and/or Feed Lot	rodeo stadium	fertilizer, manure, petroleum, solvents
811	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
812	Storage Tank	gravity driven gas tank	petroleum
813	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
814	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
815	Service Station	service station	metals, solvents, petroleum
816	Business	heating company	metals, solvents
817	Medical	dentistry	metals, solvents
818	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
819	Large Lawn	greenhouses	pesticides, fertilizer
820	Medical	dentistry	metals, solvents
821	Business	auto & body shop	metals, solvents, petroleum
822	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
823	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
824	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
825	Industry	power sub station	PCB
826	Mining	borrow pit	metals, solvents, petroleum
827	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
828	Industry	mini power station	PCB
829	Business	inspection station	PCB
830	Business	real estate, auto dealer	metals, solvents, petroleum
831	Storage Tank	gravity driven gas tank	petroleum
832	FCAF	abandoned corral	fertilizer, manure, nitrates
833	FCAF	abandoned corral	fertilizer, manure, nitrates
834	Business	beauty salon	metals, solvents
835	Business	hardware store	metals, solvents
836	Government	fire station	metals, solvents, petroleum
940	Government	transportation	metals, solvents, petroleum
837	Large Lawn	ball park	pesticides, fertilizer
838	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
839	Large Lawn	cemetery	pesticides, fertilizer
840	Large Lawn	cemetery	pesticides, fertilizer
841	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
842	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
843	Service Station	carwash	metals, solvents, petroleum
844	Industry	abandoned industry	metals, solvents, petroleum
845	Concentration of Animals and/or Feed Lot	small dairy operation	fertilizer, manure, nitrates
846	FCAF	abandoned corral	fertilizer, manure, nitrates
847	Business	lumber	metals, solvents, petroleum
848	Business	recreation equipment dealership	metals, solvents, petroleum
849	Service Station	gas station	metals, solvents, petroleum
850	Service Station	gas station	metals, solvents, petroleum
851	Business	craft store	metals, solvents
852	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
853	Business	automotive store	metals, solvents, petroleum
854	Business	massage and tanning salon	metals, solvents
855	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates

Appendix A: (continued)

SITE	POTENTIAL CONTAMINANT	LOCATION/SOURCE DESCRIPTION	POLLUTANT
856	Junk Yard/Salvage	personal junk yard	metals, solvents, petroleum
857	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
858	Business	saw sharpening business	metals, solvents
859	Business	RV storage	metals, solvents, petroleum
860	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
861	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
862	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
863	Storage Tank	gravity driven gas tank	petroleum
864	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
865	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
866	Concentration of Animals and/or Feed Lot	dairy farm	fertilizer, manure, nitrates
867	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
868	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
869	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
870	Storage Tank	gravity driven gas tank	petroleum
871	Storage Tank	gravity driven gas tank	petroleum
872	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
873	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
874	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
875	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
876	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
877	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
878	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
879	Storage Tank	2 gravity gas tanks	petroleum
880	Storage Tank	2 gravity gas tanks	petroleum
881	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
882	Business	storage sheds	metals, solvents, petroleum
883	Storage Tank	2 gravity gas tanks	petroleum
884	FCAF	abandoned corral	fertilizer, manure, nitrates
885	Storage Tank	gravity driven gas tank	petroleum
886	Large Lawn	ball park	pesticides, fertilizer
887	Large Lawn	park	pesticides, fertilizer
888	Concentration of Animals and/or Feed Lot	sheep, corral	fertilizer, manure, nitrates
889	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
890	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
891	Junk Yard/Salvage	personal junk yard	metals, solvents, petroleum
892	Storage Tank	gravity driven gas tank	petroleum
893	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
894	Storage Tank	gravity driven gas tank	petroleum
895	Government	fire station	metals, solvents, petroleum
896	FCAF	abandoned corral	fertilizer, manure, nitrates
897	Large Lawn	cemetery	pesticides, fertilizer
898	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
899	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
900	Concentration of Animals and/or Feed Lot	horse ranch	fertilizer, manure, nitrates
901	Concentration of Animals and/or Feed Lot	sheep, corral	fertilizer, manure, nitrates
902	Concentration of Animals and/or Feed Lot	sheep, corral	fertilizer, manure, nitrates
903	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
904	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
905	Industry	power sub station	PCB
906	Industry	power sub station	PCB
907	Storage Tank	gravity driven gas tank	petroleum
908	Business	auto parts store	metals, solvents, petroleum
909	Storage Tank	gravity driven gas tank	petroleum
910	Storage Tank	2 gravity driven gas tank	petroleum
911	FCAF	abandoned chicken coop	fertilizer, manure, nitrates
912	FCAF	abandoned corral	fertilizer, manure, nitrates
913	Medical	health care facility	metals, solvents
914	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
915	Storage Tank	gravity driven gas tank	petroleum
916	Large Lawn	cemetery	pesticides, fertilizer
917	Mining	gravel pit	metals, solvents, petroleum
918	FCAF	abandoned corral	fertilizer, manure, nitrates
919	FCAF	abandoned corral	fertilizer, manure, nitrates
920	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
921	Concentration of Animals and/or Feed Lot	turkey operation	fertilizer, manure, nitrates
922	Concentration of Animals and/or Feed Lot	corral	fertilizer, manure, nitrates
923	Mining	gravel pit	metals, solvents, petroleum
924	Service Station	service station	metals, solvents, petroleum

* FCAF = Former Concentration of Animals and/or Feed Lot

APPENDIX B

PREVIOUS INVESTIGATIONS

Regional Investigations During the Late 1800s

Early regional reconnaissances of the geology of the Sanpete Valley area were made by G.K. Gilbert, E.E. Howell, E.D. Cope, and C.E. Dutton. Gilbert's (1875) discussion of the regional geology included descriptions of the North Horn Formation in Wales Canyon of the San Pitch Mountains. Howell's (1875) report included discussion of the geology of the Wasatch Plateau. Cope (1880) reported on the nature of the Manti beds, which Spieker and Reeside (1925) later reassigned to the Green River Formation. Dutton's (1880) report on the geology of the high plateaus of Utah broadened knowledge concerning structure and stratigraphy in the San Pitch River drainage basin.

Early Resource Investigations

Water and coal resources became the focus of geological studies in the early 1900s. Richardson (1906) performed a reconnaissance survey of coal resources in Sanpete County; Richardson (1907) subsequently performed a reconnaissance of groundwater resources in Sanpete Valley. Clark (1914) performed a more detailed evaluation of coal resources near Wales.

U.S. Geological Survey Studies, 1925-1946

The geology of the Wasatch Plateau and adjoining areas became better understood through studies conducted by the U.S. Geological Survey, led by E.M. Spieker, in the 1920s, 1930s, and early 1940s. Spieker and Reeside (1925, 1926) discussed Cretaceous and Tertiary rock units in the Wasatch Plateau, including the Sanpete County portion. Spieker (1930, 1931, 1934) also discussed the structure of the Manti area and areas to the south of the study area, evaluated the Wasatch Plateau coal field in eastern Sanpete County, and discussed the stratigraphy of the Wasatch Formation based, in part, on his work in Sanpete County. Spieker (1936a,b, 1946; Spieker and Schoff, 1937; Spieker and Billings, 1940) concluded his U.S. Geological Survey work, before moving on to join the faculty at Ohio State University's Department of Geology, with publications on the geologic history of central Utah, including the San Pitch River drainage-basin area. Duncan (1944) mapped the Mount Pleasant coal field.

Ohio State University Investigations, 1931-1957

Students from Ohio State University (OSU) Department of Geology have worked on the geology of the western margin of the Wasatch Plateau and the San Pitch Mountains from the 1930s to the present. OSU established a geologic field station in Ephraim in the summer of 1946 (Hunt, 1950), producing more detailed geologic studies of the Cedar Hills, the San Pitch Mountains, and the Wasatch Plateau.

Schoff (1931, 1937a) studied oolites in the Green River Formation. Schoff (1937b, 1941, 1942, 1951) also investigated the geology of the Cedar Hills. Cooper (1956) studied the petrography of the Moroni Formation in the Cedar Hills. Fograscher (1956) studied the stratigraphy of the Green River and Crazy Hollow Formations in the Cedar Hills.

Gilliland (1948, 1951) mapped the geology of the Gunnison quadrangle in the southern San Pitch Mountains; Gilliland (1952, 1963) also studied the structure of the Sanpete-Sevier Valley anticline. Hunt (1948, 1950, 1954) studied the northern part of the San Pitch Mountains, including the eastern side in Sanpete County. Taylor (1948) mapped the geology of the San Pitch Mountains in the vicinity of Wales. Babisak (1949) mapped the southeastern portion of the San Pitch Mountains.

Bonar (1948) mapped the geology of the western edge of the Wasatch Plateau near Ephraim. Faulk (1948) studied the Green River Formation in the Manti-Spring City area. Washburn (1948) mapped the geology near Manti Canyon. Johnson (1949) studied the geology of the Twelvemile Canyon area. Wilson (1949) mapped the geology of the Sixmile Canyon area. Pashley (1956) studied the geology of the western edge of the Wasatch Plateau between Spring City and Fairfield. Mase (1957) studied the geology of the Indianola area of northern Sanpete County.

Spieker (1949a) compiled the work of many of his OSU students to produce a map for much of the San Pitch River drainage basin.

Structural Geology–The Great Debate

Previous work on the structural geology of central Utah, including the study area, has been the subject of much controversy. This controversy has revolved principally around the relative roles of compression and salt diapirism in the formation of structural geologic features.

Orogenic Origins

Spieker (1949a,b) postulated 14 episodes of Late Jurassic to Early Cretaceous crustal movements consisting of compressive movements interspersed with periods of normal faulting and monoclinal flexure in central Utah. Essentially, Spieker's (1949a,b) episodes of crustal movement can be grouped into: (1) pre-Tertiary orogenesis (folding and thrusting) which produced angular unconformities as bedrock was eroded from high areas to the west and deposited as conglomerates to the east, (2) Paleocene to Eocene normal faulting and monoclinal folding (including the Wasatch monocline), (3) Oligocene to Pliocene minor thrusting and folding, and (4) Pleistocene normal faulting. Spieker (1949a,b) attributed the grabens in the hinge of the Wasatch monocline and antithetic faults extending the entire length of the structure to tensional stresses associated with flexure of the monocline; he attributed folds and syngenetic faults at the base of the moncline throughout its length to one or more post-monocline-formation thrusting events.

Gilliland (1949, 1951, 1952) documented two other crustal movements, one prior to the deposition of the North Horn Formation, and the other as a late Eocene or early Oligocene compressional event that locally produced Z-folds near the base of the San Pitch Mountains. Hardy (1952) studied the Arapien Shale of central Utah and concluded that compressional tectonics was a principal factor in the development of locally folded structures, especially along the eastern side of Sevier Valley.

Armstrong (1968) defined the Sevier orogeny, to which he attributed the known thrust faults in the region.

The Rise of Diapirism

Stokes (1952, 1956, 1982) was among the first to postulate that some of the structures and stratigraphic relationships in the central Utah region resulted from diapirism in salt-bearing strata of the Arapien Shale; due to differences in specific gravity of salt and bedrock, rising diapirs formed anticlines that may be responsible for Sanpete and Arapien Valleys and structures immediately adjacent to them. Diapirism produced upturned beds and compressional features in rocks along the margins of the anticlines; subsequent exposure of the soluble salt material and highly fractured rock in the anticline cores and interaction with subsurface and surface water resulted in solution and erosion, and subsequent core collapse within the anticlines to form inverted topography. Stokes (1982) indicated the Sanpete-Sevier Valley anticline, which Gilliland (1963) mapped and attributed to compression, was evidence for his postulated diapiric anticline.

Moulton (1975) also attributed much of the structural complexity in the Sanpete-Sevier Valleys area to salt diapirs; he attributed the erosional remnants of recumbent and or mushroom-shaped folds to diapiric movement. Moulton (1975) identified a Middle Jurassic depression, west of the pre-Cretaceous "ancient Ephraim (normal) fault," which he called the Sanpete-Sevier rift, and postulated it as a depocenter with accumulation of over 8,000 feet (2,400 m) of evaporite-rich Jurassic sediments.

Baer (1976) attributed diapirism as the principal cause of the features, such as "strip-thrusting" (thin, parallel, imbricated thrusts) and "double angular uncomformities," described by Spieker and his OSU students. Baer (1976) stated that compressional structural features are almost totally absent in central Utah.

Witkind (1982, 1994) ascribed almost all structural features in the Basin and Range-Colorado Plateau transition zone of central Utah to at least three diapiric episodes–one in the Late Cretaceous, one in the late(?) Oligocene, and one extending from the late(?) Oligocene to the Pliocene or Pleistocene. Witkind (1982) described each of these episodes as divisible into three phases: (1) an intrusive phase during which salt moved upward forming the diapiric fold, (2) an erosional stage during which the diapiric fold either collapsed or subsided with subsequent removal of the remnants, and (3) a depositional stage during which younger sediments accumulated on the new surface.

Regional Tectonics Thrust Back to the Forefront

Modern structural interpretations for the San Pitch River drainage basin began with Standlee's (1982) interpretation of the structure and stratigraphy of Jurassic rocks in central Utah. Standlee (1982) postulated that regional compression followed by regional extension were the major causes of deformation in central Utah. He also identified west-directed back-thrusting along east-dipping fault zone along the east flank of the San Pitch Mountains as an important factor in the development of some features, such as the juxtaposition of dissimilar facies of the Cretaceous rocks.

Lawton and others (1997) described the Sevier orogenic belt in central Utah as consisting of four north-northwest-trending thrust plates (Canyon Range thrust, Pavant thrust, Paxton thrust, and Gunnison thrust) and two structural culminations that record crustal shortening and uplift from the late Mesozoic to the Tertiary. Synorogenic clastic rock units exposed within the central Utah sector of the Sevier thrust belt related to these episodes of thrusting include, from oldest to youngest, the Cedar Mountain Formation, San Pitch Formation, formations of the Indianola Group, and North Horn Formation (Lawton and others, 1997). This foreland-breaking sequence of thrust deformation was modified by minor out-of-sequence thrust displacement, structural culminations in the thrust-belt interior, and subsequent deformation and uplift of some of the thrust sheets following their emplacement (Lawton and others, 1997).

Weiss and Sprinkel (2000) concluded that regional diapirism "cannot be the cause of the major tectonic and sedimentary history of the Sanpete-Sevier Valley region" because: (1) the diapiric model does not predict the type of crustal shortening represented by overturning of fault-repeated strata and consistent west vergence of faults and folds, (2) the crest of the antiform in Sanpete Valley is not breached by the Arapien Shale except at its western margin, and (3) major regional deformation related to the Sevier and Laramide orogenies and Basin-and-Range extension are well documented in the central Utah region; however, they noted that diapirism of the Arapien Shale has modified some structures. Weiss and Sprinkel (2000) attribute the topographic difference between the San Pitch Mountains and Sanpete Valley to the Gunnison fault along the eastern base of the mountains. Hecker (1993) determined that the Gunnison fault has moved during the Holocene.

Economic Geology Studies of the 1960s and 1970s

Averitt (1964) summarized data on coal resources that included the Sanpete County coal fields. Pratt and Callaghan (1970) provided an overview of economic geologic resources in Sanpete County, including water, industrial minerals, metallic minerals, and fossil fuels. Doelling (1972a,b) provided detailed information on coal resources in central Utah, including Sanpete County. Ritzma (1972) provided information on rock units penetrated by an oil/gas-test well drilled near Moroni.

Modern Geologic Mapping

The geologic map used for this study (figure 5 and plate 3) was compiled from 1:100,000-scale maps based on geologic reports described above with extensive new work: Witkind and others (1987) compiled the Manti 30 x 60 minute quadrangle, and Witkind and Weiss (1991) compiled the Nephi 30 x 60 minute quadrangle. More detailed recent geologic mapping includes: (1) Mattox's (1987) provisional map of the Hells Kitchen SE quadrangle in the northern San Pitch Mountains, (2) Banks' (1991) geologic map of the Fountain Green North quadrangle in the northwestern arm of Sanpete Valley, (3) Jensen's (1993) interim map of the Fairview quadrangle in northeastern Sanpete Valley, (4) Weiss' (1994) map of the Sterling quadrangle in southern Sanpete Valley and northern Arapien Valley, (5) Fong's (1991, 1995) maps of the Fountain Green South quadrangle in northwestern Sanpete Valley, (6) Lawton and Weiss' (1999) map of the Wales quadrangle in west-central Sanpete Valley, and (7) Weiss and Sprinkel's (2000) interim geologic map of the Manti quadrangle.

APPENDIX C

GROUND-WATER CONDITIONS

Introduction

Ground water in the Sanpete Valley area is in two types of aquifers: fractured bedrock and unconsolidated deposits. Ground water in the Sanpete Valley area is obtained principally from unconsolidated deposits of the valley-fill aquifer (Wilberg and Heilweil, 1995). However, fractured-rock aquifers are also important sources of water in Sanpete Valley (Richardson, 1907; Robinson, 1971); they yield water to springs in both the Wasatch Plateau and the San Pitch Mountains, as well as some wells in Sanpete Valley (Wilberg and Heilweil, 1995).

Fractured-Rock Aquifers

Though few wells are drilled into fractured-rock aquifers, mostly because the valley-fill aquifer in Sanpete Valley is productive (Robinson, 1971), they are important sources of water, especially to springs. Table 7 summarizes the hydrostratigraphy of fractured-rock units in the San Pitch River drainage basin, and table C1 provides information on the quantity and quality of water issuing from selected fractured-rock springs.

Occurrence

Fractured-rock aquifers are under both unconfined and confined conditions in the Wasatch Plateau and San Pitch Mountains, but are generally under confined conditions beneath the valley fill (Robinson, 1971). Water in fractured rock is primarily from joints, faults, and bedding planes, and, to a lesser extent, pore spaces in clastic rocks or dissolution channels in carbonate rocks.

The Indianola Group, Price River Formation, Flagstaff Limestone, and Green River Formation yield water to some of the major springs along the margins of Sanpete Valley (table C1) (Robinson, 1971), and water is found locally in almost all of the fractured-rock units in the San Pitch River drainage basin. Big Springs, located northwest of Fountain Green, is the largest fractured-rock spring in Sanpete Valley, with discharges exceeding 12,500 gallons per minute (788 L/s) in the mid-1980s (Utah Division of Wildlife Resources, Fountain Green Fish Hatchery, verbal communication, 1989, in Wilberg and Heilweil, 1995).

Artesian fractured-rock wells drilled through valley fill into limestone and sandstone of the Green River Formation are an important source of irrigation water near Manti, and from Spring City to Fairview (Robinson, 1971). An artesian well about 2 miles (3.2 km) southeast of Moroni, perforated in the Flagstaff Limestone from 2,280 to 2,406 feet (695 and 733 m) depth, had the highest yield of all fractured-rock wells (1,350 gallons per minute [85 L/s]) (Utah State Engineer's Office, written communication, 1980, in Wilberg and Heilweil, 1995).

Aquifer Characteristics

Aquifer characteristics such as transmissivity, storativity, and hydraulic conductivity are variable in the fractured-rock aquifers; Robinson (1971) reports a wide range of transmissivities for several different formations. For example, transmissivities from the Green River Formation range from 400 square feet per day (125 m^2/day) to 134,000 square feet per day (41,000 m^2/day). The higher value is likely the result of the well intersecting solution channels in oolitic limestone layers within the Green River Formation. Other fractured-rock formations have transmissivities of less than 7,800 square feet per day (2,400 m^2/day) (Robinson, 1971).

Precipitation in the San Pitch Mountains, Cedar Hills, and Wasatch Plateau is the primary source of recharge to both fractured-rock and unconsolidated aquifers in the San Pitch River drainage basin (Richardson, 1907; Robinson, 1971), but the trans-basin diversions also account for some recharge (Robinson, 1971). Water from precipitation either runs off in streams or percolates through the thin surficial deposits and recharges fractured-rock aquifers. Water then travels through fractures and pore spaces generally toward the valley. In the San Pitch Mountains, some bedrock ground water discharges in springs at the edge of the valley fill; along the western side of the valley, faults may provide a control on the location of springs (Richardson, 1907). A notable example is Big Springs, one mile (1.6 km) west of Fountain Green, likely supplied by water traveling downdip in the Indianola Group (Robinson, 1971), and ultimately discharged along a fault zone (Richardson, 1907). In the folded strata of the Wasatch monocline, water also travels toward Sanpete Valley. Water in the monocline discharges to both ephemeral and perennial mountain streams, as well as to springs along the mountain front (Robinson, 1971).

Ground water in fractured rock that is not discharged to the surface as springs or base flow to streams likely flows into or under the valley fill. Water from fractured rock may be a source of recharge to, and, in the center of the valley, contribute to upward hydraulic head in, the valley-fill aquifer (Robinson, 1971). Three examples of evidence for ground-water flow and local confined conditions in bedrock include: (1) sinkholes and solution channels in the Wasatch Plateau, (2) artesian wells in bedrock on the Wasatch Plateau, and (3) artesian wells drilled into bedrock underlying valley fill near Manti and Spring City (Robinson, 1971). Wilberg and Heilweil (1995, p. 14) assume ground-water recharge to the valley-fill aquifer from fractured-rock aquifers is minimal.

Table C1. Fractured-rock springs, Sanpete Valley, Sanpete County, Utah (modified from Robinson, 1968).

Location	Name	Bedrock Unit	Yield (gallons per minute) e=estimated m=measured r=reported	Date of measurement	Specific Conductance (micromhos/cm at 25°C)
(D-13-5) 33ada-S1	Fairview Springs	North Horn Formation (Upper Cretaceous and Paleocene)	210m	10-10-66	470
(D-14-2) 2bab-S1	Big Springs	Indianola Group (Upper Cretaceous)	5,566r 3,750r 3,200r 4,300r	— 1-24-66 4-27-66 8-9-66	— 440 — 430
9bdb-S1	Cool Spring	Indianola Group (Upper Cretaceous)	25e	8-10-66	470
23bda-S1	Birch Creek Springs	Indianola Group (Upper Cretaceous)	688r 374m 432m 468m 468m	— 1-14-66 5-3-66 8-4-66 11-7-66	— 580 510 560 530
26ddc-S1	Bailey Spring	Indianola Group (Upper Cretaceous)	50m	1-17-66	580
35aab-S1	Lauritz Tunnel Spring	Indianola Group (Upper Cretaceous)	150m	1-17-66	540
35aab-S2	Christensen Spring	Indianola Group (Upper Cretaceous)	15e	1-17-66	540
(D-14-3) 14dcc-S1	Apple Tree Spring	andesite pyroclastics (Moroni Formation of Schoff (1938)) (middle or upper Tertiary)	3.5m	8-29-66	430
(D-15-2) 2ada-S1	Freedom Spring	Indianola Group (Upper Cretaceous)	436r 440m 550m 500e 440m	— 1-21-66 5-3-66 8-3-66 11-7-66	— 420 450 460 430
13bbc-S1	Brewer’s Spring (North Spring)	Indianola Group (Upper Cretaceous)	202r 234m 212m	— 1-21-66 5-3-66	— 420 390
(D-15-2) 3bbc-S1	Brewers Spring (North Spring)	Indianola Group (Upper Cretaceous)	207m 190m	8-3-66 11-7-66	430 420
13cdb-S1	Middle Spring	Indianola Group (Upper Cretaceous)	50m	1-8-65	510
24bda-S1	South Spring	Indianola Group (Upper Cretaceous)	125e	1-8-65	570
24bdb-S1	Unnamed	Indianola Group (Upper Cretaceous)	25e	1-8-65	540
26acb-S1	Lime Kiln Spring	North Horn Formation (Upper Cretaceous and Paleocene)	125e	1-20-65	660
9acb-S1	Moroni Spring	andesite pyroclastics (Moroni Formation of Schoff (1938)) (middle or upper Tertiary)	225r	9-8-66	830
(D-16-2) 12aac-S1	Lamb’s Spring	Castlegate Sandstone (Upper Cretaceous)	30e	12-8-66	1,000
(D-16-4) 13adb-S1	Old Ox Spring	North Horn Formation (Upper Cretaceous and Paleocene)	52m	11-16-66	500

Table C1 *(continued)*

Location	Name	Bedrock Unit	Yield (gallons per minute) e=estimated m=measured r=reported	Date of measurement	Specific Conductance (micromhos/cm at 25°C)
(D-17-4) 16dcd-S1	Big Spring (Upper Cretaceous and Paleocene)	North Horn Formation	675e	6-28-66	380
13cad-S1	Crystal Springs (Livingston Warm Springs)	Flagstaff Limestone (upper Paleocene and lower Eocene(?))	275r	—	—
			425m	10-20-65	860
			374m	1-27-66	860
			382m	4-27-66	880
			360m	8-3-66	900
			414m	11-4-66	850
14cdb-S1	Milt's Springs	Sanpete Formation (Cretaceous)	411m	11-16-65	860
22cb-S	Saleratus Spring	Crazy Hollow Formation of Spieker (1949) (upper (?) Eocene)	560r	—	—
			265m	8-26-65	1,200
(D-17-4) 22cb-S	Saleratus Spring	Crazy Hollow Formation of Spieker (1949) (upper (?) Eocene)	423m	10-15-65	1,200
			360m	1-29-66	1,100
			292m	4-26-66	1,200
			297m	8-2-66	1,200
			283m	11-4-66	1,100
23aac-S1	Stinking Springs (Cretaceous)	Funk Valley Formation	225e	5-5-66	1,900
(D-18-2) 35d-S	Morrison Coal Mine Tunnel Spring	Unknown sandstone	2,540r	—	—
			1,350m	8-24-65	620
			1,830m	10-15-65	—
			1,130m	1-27-66	660
			1,050m	4-26-66	670
			1,130m	8-2-66	660
			930m	11-4-66	600
(D-18-4) 20bb-S	Hougaard Springs	Flagstaff Limestone (upper Paleocene and lower Eocene (?))	900-1,000r	6-28-66	497
(D-19-2) 1dbc-S1	Cove Spring	Flagstaff Limestone (upper Paleocene and lower Eocene (?))	75e	8-19-65	500
4dca-S1	Peacock Spring (Nine Mile Warm Spring)	Flagstaff Limestone (upper Paleocene and lower Eocene (?))	900r	—	—
			1,260m	8-19-65	690
			490m	12-6-65	—
			460m	2-3-66	620
			346m	4-26-66	710
			428m	7-28-66	660
			418m	11-4-66	650
8dcb-S1	Little Nine Mile Spring	Green River Formation (lower and middle Eocene)	240m	8-17-65	1,300
(D-19-2) 9cbb-S1	Nine Mile Cold Spring	Green River Formation (lower and middle Eocene)	990r	—	—
			1,410m	8-17-65	1,100
			1,300m	10-15-65	—
			780m	1-27-66	1,200
			900m	4-26-66	1,300
			905m	8-2-66	1,300
			805m	11-4-66	1,100
20ddd-S1	Spannard Spring	Green River Formation (lower and middle Eocene)	900e	7-15-65	1,100

data unavailable indicated by dash

Water Quality

Water quality from fractured-rock aquifers in the San Pitch River drainage varies. Robinson (1971) attributed high specific conductances in water in fractured-rock wells along the east-central margin of Sanpete Valley to the Green River and Crazy Hollow Formations, and indicated that some of these wells were too saline for culinary use; for instance, a specific conductance of 4,800 micromhos per centimeter at 25˚C (about 3,200 mg/L) was measured from a 1,500-foot- (457 m) deep well north of Mount Pleasant. Evaporites from the Arapien Shale beneath the San Pitch Mountains likely increase ground-water salinity in southwestern Sanpete Valley (Richardson 1907; Robinson, 1971). Table C1 provides a summary of specific conductance from selected fractured-rock springs.

Valley-Fill Aquifer

Occurrence

Ground water in the valley-fill aquifer of Sanpete Valley occurs under confined and unconfined conditions in unconsolidated deposits (figure 6) (Robinson, 1971). In areas where the principal valley-fill aquifer is under confined conditions, it is generally overlain by a shallow unconfined aquifer (figure 6). Based on water-well data, the thickness of unconsolidated fill is estimated to be at least 500 feet (1500 m) in the widest part of Sanpete Valley, between Ephraim and Moroni (Robinson, 1971).

The valley fill consists primarily of interfingered layers of clay, silt, sand, and gravel. Sediments are generally coarser grained in alluvial fans along the mountain fronts and finer grained in the central portions of the valley; provenance controls, to some extent, the composition and grain size of the valley-fill material. For example, tuff and andesite of the Moroni Formation in the Cedar Hills, Tertiary shale and mudstone in the Wasatch Plateau, and Jurassic shale and mudstone along the base of the San Pitch Mountains, contribute finer grained sediment than does Mesozoic conglomerate in the Wasatch Plateau and San Pitch Mountains. Along the eastern valley margin, alluvial-fan sand and gravel extend farther into the valley, and in the western arm of Sanpete Valley near Fairview materials are predominantly coarse with only a few fine-grained lenses (figure C1). Thick, fine-grained layers in the valley-fill aquifer extend up to the base of the San Pitch Mountains at the western edge of Sanpete Valley; between Wales and Spring City valley fill is predominantly fine grained with coarse-grained lenses (figure C2). Farther south, near Ephraim, coarse-grained alluvial material dominates the eastern margin of the valley and forms relatively continuous layers within the finer grained material in the valley center (figure C3).

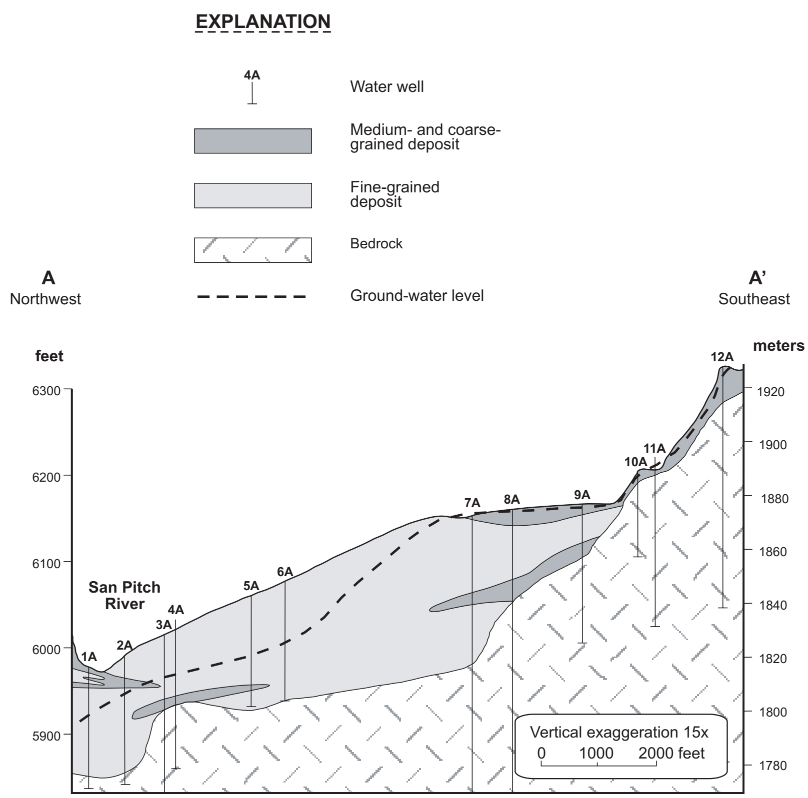

__Figure C1.__ Diagrammatic cross section showing stratigraphy in the valley-fill deposits north of Fairview, Sanpete Valley, Sanpete County, Utah. Location of cross section is shown in figure 5.

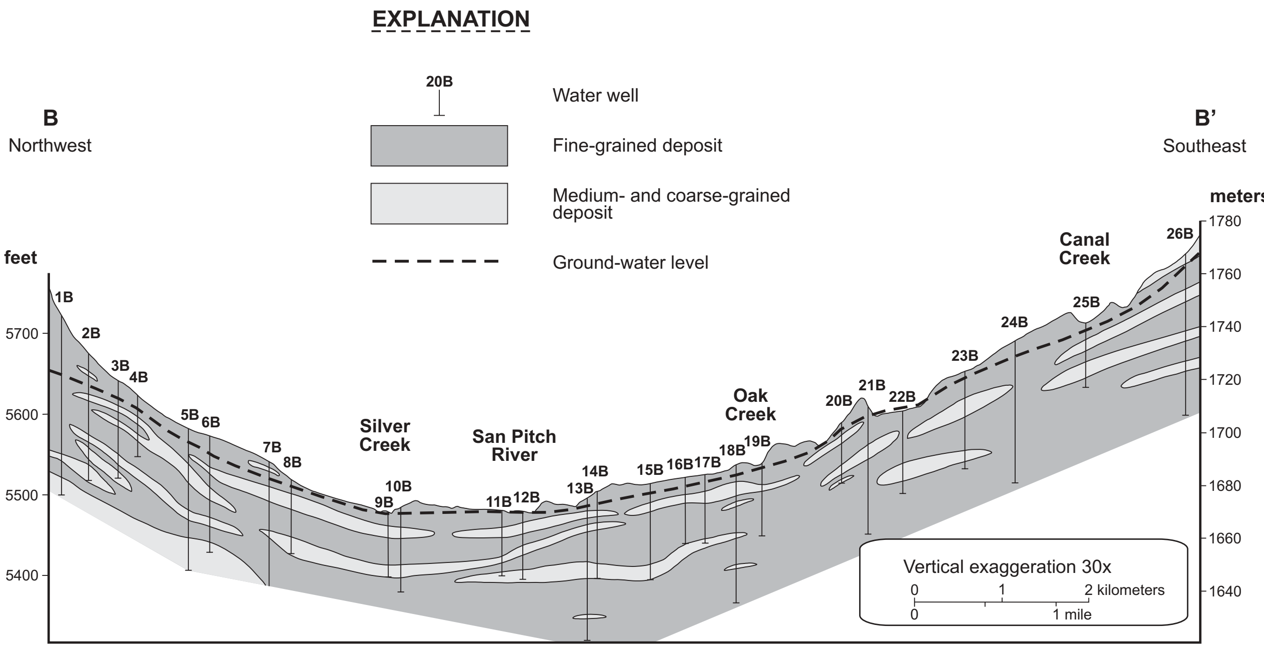

Figure C2. *Diagrammatic cross section showing stratigraphy in the valley-fill deposits between Wales and Spring City, Sanpete Valley, Sanpete County, Utah. Location of cross section is shown in figure 5.*

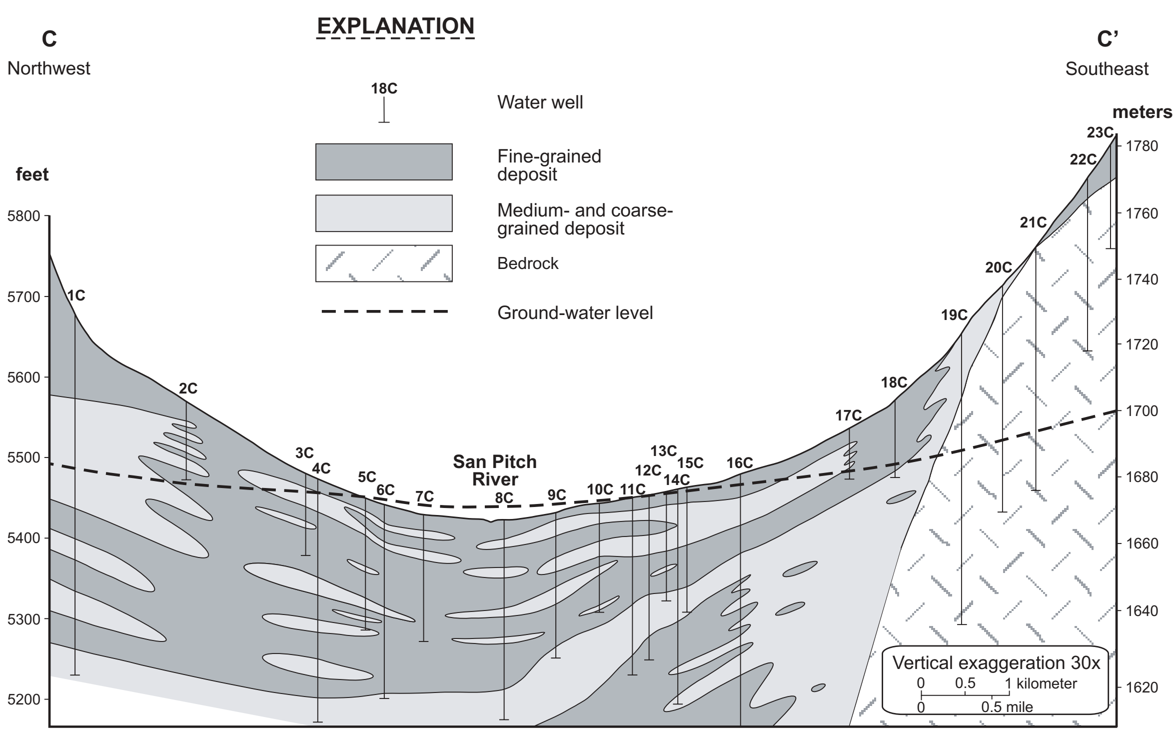

Figure C3. *Diagrammatic cross section showing stratigraphy in the valley-fill deposits near Ephriam, Sanpete Valley, Sanpete County, Utah. Location of cross section is shown in figure 5.*

Confined conditions exist where thick silt and clay confining beds overlie coarse sediments along the San Pitch River below its confluence with Silver Creek, and along Silver Creek in the northwestern arm of the valley. In the northern part of this area of thick confining beds, to about 3 miles (5 km) south of Wales, there is one generally uniform confined aquifer, 100 to 200 feet (30-60 m) deep (Robinson, 1971). To the south, several distinct confining layers are present in the valley-fill aquifer (figure C3), and wells of different depths in proximity to each other commonly have different hydraulic heads (Robinson, 1971). These distinct confining layers are of limited extent, but overlap and combine to form a generally continuous, but leaky, confining layer; leakage between the distinct confining layers described above decreases with increasing depth (Wilberg and Heilweil, 1995).

Areas where confining layers are thicker than 20 feet (6 m) having an upward ground-water gradient are called discharge areas, and contain wells that are artesian, at least seasonally (Anderson and others, 1994). The primary discharge area follows the lowlands along the San Pitch River from 1 mile (1.6 km) west of Mount Pleasant to Gunnison Reservoir, but much of the northwestern arm along Silver Creek is also a discharge area (figure 6) (Snyder and Lowe, 1998). Secondary recharge areas are where confining layers are thicker than 20 feet (6 m) and the ground-water gradient is downward (Anderson and others, 1994). Fine-grained sediments in alluvial-fan deposits form a band of secondary recharge areas along the eastern edge of southern Sanpete Valley; along the northern San Pitch Mountains alluvial-fan deposits are coarser than those on the eastern side of the valley, and secondary recharge areas are present only near the distal ends of alluvial fans (figure 6) (Snyder and Lowe, 1998).

Unconfined conditions exist in the northeastern arm of Sanpete Valley, north of Fairview, where coarse-grained material predominates (figure C1), and along the base of the Wasatch Plateau on the eastern side of Sanpete Valley. In these unconfined areas, depth to ground water ranges from 100 feet (30 m) in alluvial fans to 10-30 feet (3-9 m) near the San Pitch River (Robinson, 1971). The valley-fill aquifer is unconfined only in a narrow band along the western side of Sanpete Valley, where water is generally less than 60 feet (18 m) beneath the surface of the alluvial fans (Robinson, 1971). Unconfined conditions exist in Arapien Valley (Robinson, 1971). Because of the lack of thick (20 feet [6 m]), protective clay layers, these primary recharge areas are vulnerable to surface sources of ground-water contamination (Lowe and Snyder, 1996). The boundary between confined and unconfined conditions is indefinite and gradational, and shifts as the potentiometric surface of the valley-fill aquifer system rises and falls with changes in recharge and discharge (Snyder and Lowe, 1998).

Well Yields

Of the more than 1,500 wells in the Sanpete Valley valley-fill aquifer on record with the Utah Division of Water Rights in 1967, approximately two-thirds were small diameter (4 inches [5 cm] or less), 150- to 250-foot-deep (46-76 m) flowing wells primarily used for stock watering (Robinson, 1971). Yields in these flowing wells ranged from a trickle to possibly as much as 265 gallons per minute (17 L/s); the well with the high yield is interpreted from a gamma-ray log to be completed in Pleistocene and Holocene deposits, but no information exists for the bottom 59 feet (18 m) of the 290-foot-deep (88 m) well (Robinson, 1968). Several flowing wells in the valley-fill aquifer yielded up to 10 gallons per minute (0.6 L/s) (Robinson, 1968).

About 70 wells were large-diameter wells, 10 to 16 inches (25-41 cm) in diameter, 150 to 300 feet (46-91 m) deep, equipped with large-discharge turbine pumps, and having yields ranging between 200 and 1,200 gallons per minute (13-77 L/s). These wells are primarily used for irrigation (Robinson, 1971). More than 400 were medium-diameter wells, 4 to 10 inches (5-25 cm) in diameter (Robinson, 1971).

The average annual well withdrawal from 1963 to 1988 was about 10,300 acre-feet (12.7 hm^3); about 6,300 acre feet (7.8 hm^3) was from pumped wells and about 4,000 acre-feet (4.9 hm^3) was from flowing wells (Wilberg and Heilweil, 1995). Annual withdrawal, especially from the large pumped wells, varies greatly with annual precipitation because ground water is used to supplement surface-water irrigation (figure C4) (Robinson, 1971). Total withdrawal from 55 pumped wells ranged from 1,200 to 12,800 acre-feet per year (1.5-15.8 hm^3/yr) from 1963 to 1989; total discharge from flowing wells, based on measurements of flow from 184 wells from 1965 to 1967 (Robinson, 1968) and remeasured flow from 19 of those wells in 1989, ranged from 1,300 to 4,500 acre-feet per year (1.6-5.5 hm^3/yr) from 1963 to 1989 (Wilberg and Heilweil, 1995).

Aquifer Characteristics

Transmissivity varies widely within the valley-fill aquifer. Robinson (1971) reported a range of 550 to 50,000 square feet per day (170-15,600 m^2/day) from data for 10 aquifer tests and specific capacity data for more than 40 wells. The specific capacities for wells completed in the valley-fill aquifer ranged from 3 to 120,000 gallons per minute per foot of drawdown (54-278,554 m^2/d). Low values of transmissivity and specific capacity are typically from artesian aquifers with thin sand and gravel layers or aquifers with clay and silt mixed throughout; high values are from alluvial fans where the sediments are coarser, but then decrease toward the edges of the valley as valley-fill deposits thin. Hydraulic conductivity values for the valley-fill aquifer, based on Robinson's (1971) specific capacity data, range from 6 to 99 feet per day (2-30 m/d) (Wilberg and Heilweil, 1995). Storage coefficient values for the valley-fill aquifer range from 0.00007 to 0.0029 (Robinson, 1971).

Potentiometric Surface

General: The potentiometric surface of ground water in the valley-fill aquifer is irregular and depends on the well depth, season, and the year water-level measurements are made (Robinson, 1971). In unconfined parts of the aquifer, the potentiometric

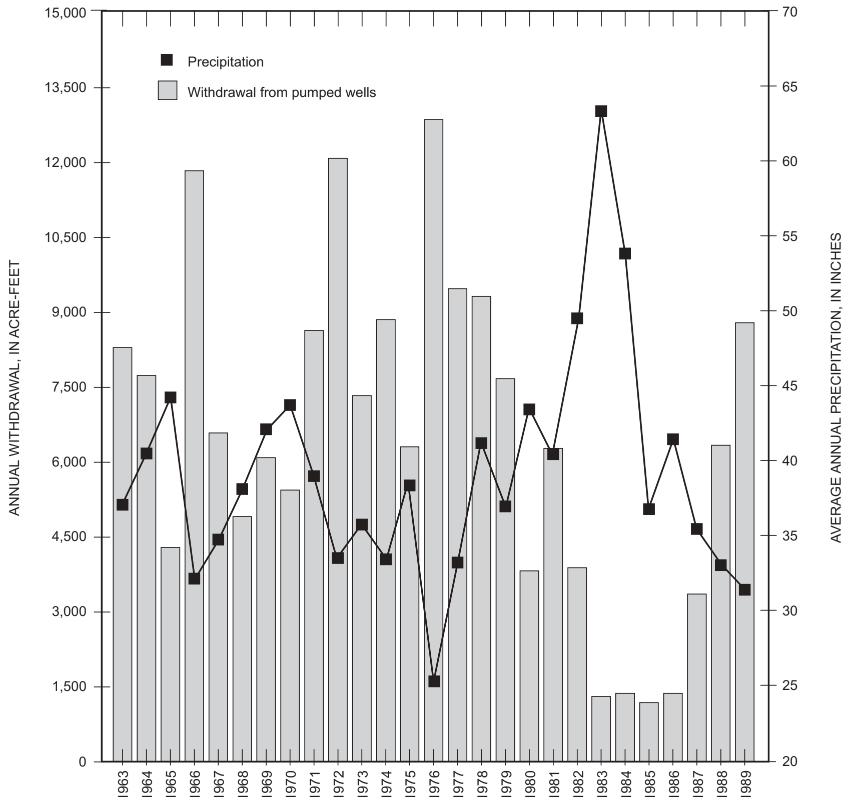

Figure C4. *Annual ground-water withdrawals from pumped wells in Sanpete Valley, Sanpete County, Utah, versus precipitation at Meadows climatic station. Wasatch Plateau, Utah, calendar years 1963-1989 (from Wilberg and Heilweil, 1995).*

surface corresponds to the water table; in the confined parts of the aquifer, the potentiometric surface represents the hydrostatic pressure, or head, a parameter controlling the elevation to which water will rise in wells. The potentiometric surface indicates horizontal ground-water flow direction, hydraulic gradient, and a predictable depth to water in wells in the unconfined portion of the aquifer. The potentiometric surface conforms in a general way to the contour of the valley floor, but hydraulic gradients are flatter; for instance near Mount Pleasant the slope of the ground is about 170 feet per mile (32 m/km) whereas the slope of the potentiometric surface is about 95 feet per mile (18m/km) (Richardson, 1907).

Ground-water flow direction: Ground-water flow is generally from the higher elevation recharge areas to lower elevation discharge areas. Ground water generally flows westward from the Wasatch Plateau and eastward from the San Pitch Mountains toward the San Pitch River and Silver Creek, and then southward toward Gunnison Reservoir. In Arapien Valley, ground water flows westward from the Wasatch Plateau toward the valley center and then northward toward Ninemile Reservoir (Robinson, 1971, plate 2). Vertical ground-water movement is downward in valley-margin recharge areas and upward in discharge areas in the central parts of the valley (Wilberg and Heilweil, 1995).

Water levels in wells: Depth to ground water in wells ranges from near the ground surface in the central portion of the valley along the San Pitch River from Fountain Green to Gunnison (Richardson 1907, plate 6), to over 60 feet (18 m) along the base of the San Pitch Mountains and 100 feet (30 m) along the base of the Wasatch Plateau (Robinson, 1971, plate 2). In the discharge area, which represents approximately 60 percent of the land surface of Sanpete Valley, deep wells have higher potentiometric surfaces than shallow wells; in the Ephraim-Chester area, 100-foot-deep (30 m) wells have artesian heads 3 to 10 feet (1-3 m) above the ground surface while 200- to 300-foot-deep (61-91 m) wells have artesian heads as much as 30 feet (9 m) above the ground surface (Robinson, 1971).

Changes in water levels: The level at which water stands in wells in the valley-fill aquifer varies in response to both seasonal and long-term changes in the hydrostatic pressure of the ground water. Changes in hydrostatic pressure in the valley-fill aquifer are due to: (1) changes in the amount of water seasonally recharged from streams (Richardson, 1907), (2) changes in the amount of water seasonally and annually withdrawn from pumping wells (Robinson, 1971), and (3) longer term, climatically controlled changes in recharge from precipitation in the drainage basin and discharge by evapotranspiration (Wilberg and Heilweil, 1995).

Seasonal changes in water levels occur when runoff from mountain streams declines and irrigation from pumped wells begins (Richardson, 1907). A general trend of increasing water levels exists during high-runoff periods from April or May to

July, followed by a period of declining water levels from July to about the following April due mostly to down-valley drainage, but also due in part to pumping during the irrigation season and summer increases in evapotranspiration (Robinson, 1971). In the Mount Pleasant-Spring City area, these seasonal changes in ground-water levels are between 10 and 20 feet (3-6 m) (Robinson, 1971).

Long-term changes in water level depend on annual average precipitation and evapotranspiration, and on average annual well pumpage. Water levels in wells decreased steadily in the late 1980s because of decreased surface-water runoff during a period of less-than-normal precipitation accompanied by increased ground-water withdrawals to meet irrigation requirements; this followed a period where water levels rose as much as 32 feet (10 m) during greater-than-normal precipitation in the early to mid-1980s (Wilberg and Heilweil, 1995). Overall, average annual ground-water levels have declined as much as 11 feet (3.4 m) in some areas of Sanpete Valley between 1970 and 2000 (figure C5), but over most of the valley water- level declines have been less than 7 feet (2.1 m) (Burden and others, 2000).

Recharge

The source of most water in the valley-fill aquifer is, directly or indirectly, the annual average 800,000 acre-feet (986 hm^3) of precipitation that falls within the San Pitch River drainage basin, but the transbasin diversions that bring surface water from the Colorado River drainage and ground-water inflow from other drainage basins through fractured-rock units that bound the basin are also possible sources of recharge (Robinson, 1971). However, of the estimated 115,000 acre-feet (142 hm^3) of average annual precipitation that falls on the floor of Sanpete Valley above Gunnison Reservoir (Robinson, 1971), only about 15,000 acre-feet (18.5 hm^3) is estimated to provide recharge to the valley-fill aquifer (table C2) (Wilberg and Heilweil, 1995), because most of the precipitation is consumed by evapotranspiration before entering the aquifer system.

Streams are the main source of recharge to the basin-fill aquifer, with the majority located in the upper portions of the highly permeable alluvial-fan deposits at the mouths of canyons along the margins of the valley (Robinson, 1971). Most of the recharge from surface water is from perennial streams flowing from the Wasatch Plateau on the east side of Sanpete Valley, although the many smaller drainages entering the valley from the San Pitch Mountains on the west contribute some intermittent recharge (Wilberg and Heilweil, 1995), especially after snowmelt or during major precipitation events. Estimated surface-water recharge from streams and springs to the San Pitch River drainage basin is about 116,000 acre-feet per year (143 hm^3/yr), with approximately 54,000 acre-feet (67 hm^3) of surface water leaving the drainage basin annually (Robinson, 1971). Most surface-water inflow is diverted for irrigation purposes; recharge to the valley-fill aquifer from streams is estimated between 30,000 and 58,800 acre-feet per year (37 and 72.5 hm^3/yr) (table C2) (Wilberg and Heilweil, 1995).

Excess irrigation water, either diverted from streams or pumped from wells, is also an important source of recharge to the valley-fill aquifer, especially along the valley margins where unconsolidated deposits are more permeable (Robinson, 1971). About 116,900 acre-feet per year (144 hm^3/yr) of water is used for irrigation in Sanpete Valley above Gunnison Reservoir; about 29,000 acre-feet per year (36 hm^3/yr) of unconsumed irrigation water recharges the valley-fill aquifer (table C2) (Wilberg and Heilweil, 1995).

Subsurface inflow from fractured-rock units surrounding the San Pitch River drainage basin may contribute a relatively small amount of recharge to the valley-fill aquifer in Sanpete Valley. For example, the southeast-dipping Indianola Group in the northern San Pitch Mountains conveys a “sizable” quantity of water into Sanpete Valley from the Juab Valley drainage basin to the west (Bjorklund and Robinson, 1968, p. 40; Robinson, 1971, p. 21). However, Wilberg and Heilweil (1995) considered flow from fractured-rock units as minimal, and primarily providing discharge to springs and streams above the valley-fill/fractured rock contact, which they modeled as a no-flow boundary; the ground-water budget in table C2 reflects this hypothesis.

Discharge

Ground water is discharged from the valley-fill aquifer by evapotranspiration, seepage to the San Pitch River, wells, and alluvial-spring discharge (Wilberg and Heilweil, 1995). Much of the discharge from seepage to the San Pitch River and the alluvial-spring discharge likely contributed to the 54,000 acre-feet per year (67 hm^3/yr) surface flow out of the San Pitch River drainage basin as estimated by Robinson (1971). The average annual discharge from the valley-fill aquifer above Gunnison Reservoir ranges from 76,000 to 224,000 acre-feet per year (94-275 hm^3/yr) (Wilberg and Heilweil, 1995).

Evapotranspiration is about 41,000 to 116,000 acre-feet per year (50.6-143 hm^3/yr) of annual average discharge (table C2) (Wilberg and Heilweil, 1995). Robinson (1971) estimated that phreatophytes, principally saltgrass, wiregrass, greasewood, and rabbitbrush, covered about 45,200 acres (18,300 hm^2) of land in Sanpete Valley in the mid-1960s; they grew mostly southwest of Manti where Sanpete Valley narrows and is constrained by bedrock outcrops which impede most ground-water flow out of the valley. In this area, confined ground water is forced to the surface and forms a large marshy area extending as far north as Manti, about 2 miles (3.2 km) north of the north end of Gunnison Reservoir (Snyder and Lowe, 1998). This marshy area once extended to near Ephraim, about 8 miles (13 km) north of Gunnison Reservoir (Robinson, 1971). Phreatophytes, as shown on plate 4, currently cover about 21,400 acres (8,700 hm^2). However, Wilberg and Heilweil (1995) consider the approximately 24,600 acres (10,000 hm^2) of irrigated pasture and grass hay categories shown on plate 4 to be generally phreatophytic.

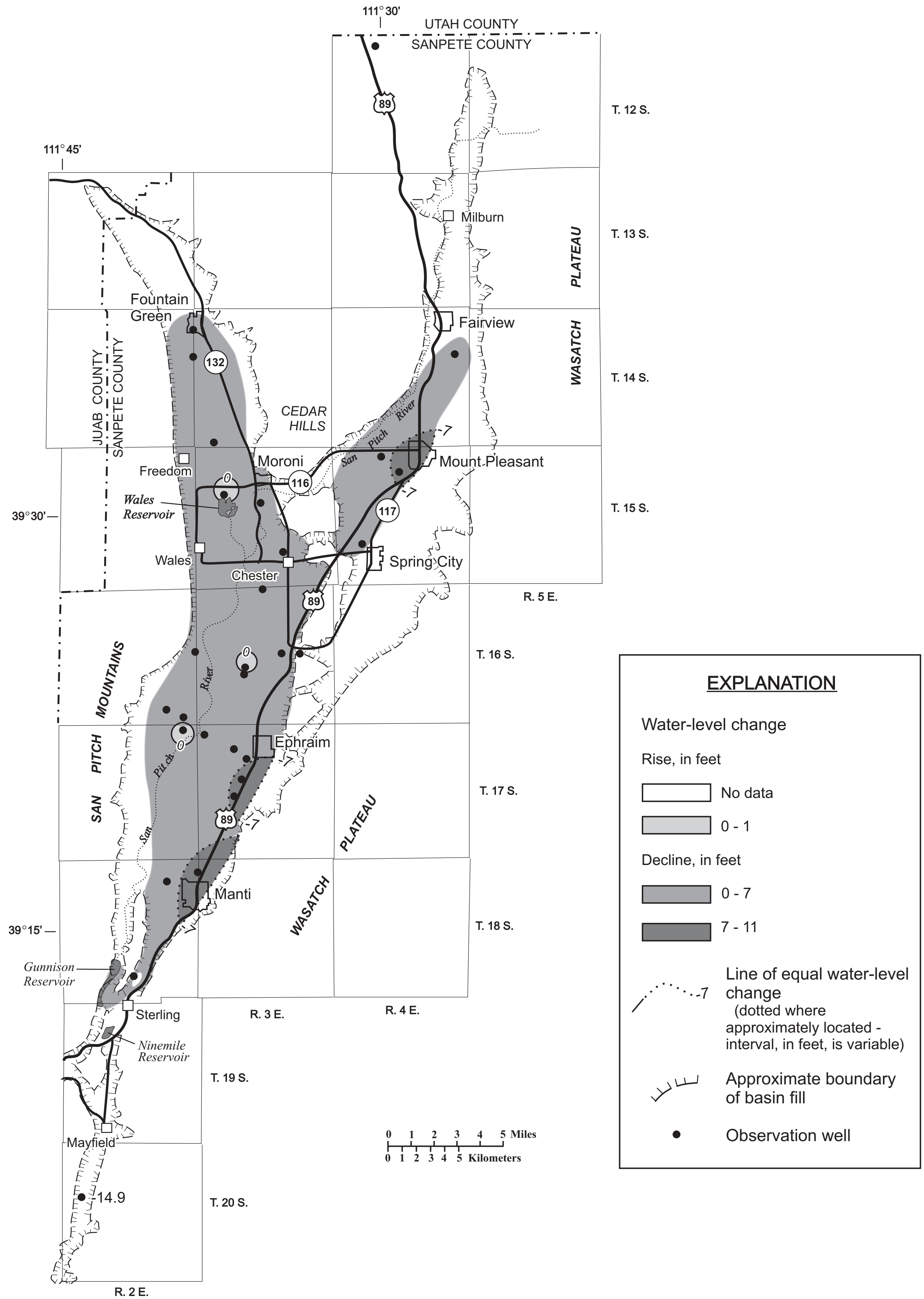

Figure C5. *Change in water levels from March 1970 to March 2000, Sanpete Valley, Sanpete County, Utah (modified from Burden and others, 2000).*

Table C2. *Components of the ground-water budget for the valley-fill aquifer in Sanpete Valley, Sanpete County, Utah (from Wilberg and Heilweil, 1995).*

Component	Measured or estimated (acre-feet per year)	Steady-state calibration (acre-feet per year)
Recharge		
Seepage from tributaries	28,500-57,000	34,500
Infiltration of unconsumed irrigation water	29,000	29,000
Infiltration of precipitation on the valley floor	15,000	15,000
Seepage from the San Pitch River	1,500-1,800	400
Subsurface inflow from head-dependent cells	unknown	200
Total recharge (rounded)	74,000 - 102,800	79,100
Discharge		
Evapotranspiration	41,000-116,000	48,000
Seepage to the San Pitch River	18,500-80,300	17,200
Withdrawals from wells	5,200-16,800	10,300
Withdrawals from springs	11,000	3,600
Total discharge (rounded)	76,000 - 224,000	79,100

Robinson (1971) conducted seepage runs (multiple water-flow measurements along a stream stretch to obtain an estimate of recharge to or discharge from ground water) on the San Pitch River in 1966 and determined that the major areas of surface-water gain from ground water were located just north of Fairview, west of Mount Pleasant to Moroni, above the bridge west of Ephraim, and within a phreatophyte patch north of Gunnison Reservoir. During 1988 seepage runs between Milburn and Gunnison Reservoir, most ground water discharged to the San Pitch River in the reach just south of Milburn to near Moroni (Sandberg and Smith, 1995). Ground-water discharge to the San Pitch River is estimated to be from 18,500 to 80,300 acre-feet per year (23-99 hm^3/yr) (Wilberg and Heilweil, 1995).

Ground-water discharge to wells is discussed above in the Well Yields section. Discharge from the valley-fill aquifer is about 4,000 acre-feet per year (5 hm^3/yr) from flowing wells and ranges from 1,200 to 12,800 acre-feet per year (1.5-16 hm^3/yr) from pumped wells (table C2) (Wilberg and Heilweil, 1995).

Robinson (1968, table 2) reported discharge from springs issuing from Quaternary alluvium scattered through Sanpete Valley (table C3). Wilberg and Heilweil (1995) estimate discharge from these springs to be about 11,000 acre-feet per year (13.6 hm^3/yr).

Water Quality

Ground-water quality in Sanpete Valley is generally good and suitable for most uses; table 8 summarizes ground-water quality classes based on total-dissolved-solids concentrations, and the relationship of total-dissolved-solids concentrations to specific conductance in Sanpete Valley. Ground water in the valley-fill aquifer generally contains less than 600 mg/L total dissolved solids (Wilberg and Heilweil, 1995), although many wells completed in the valley-fill aquifer yield water classified as moderately to very hard (averaging 320 mg/L calcium and/or magnesium) (Robinson, 1971). Ground water in the valley-fill aquifer is generally a mixed type containing calcium, sodium, magnesium, and bicarbonate ions; however, water from many wells, especially shallow ones on the west side of the valley, is a mixed type containing magnesium, sodium, sulfate, and chloride ions (Wilberg and Heilweil, 1995).

The type of water and quantity of dissolved solids is influenced by local geology. High total-dissolved-solids concentrations and high sulfate and chloride concentrations in ground water along the west side of Sanpete Valley are likely due to flow of water through Jurassic Arapien Shale containing soluble salts and gypsum, whereas ground water flowing through limestone is generally high in carbonates (Richardson, 1907). Water from shallow wells, especially in irrigated areas, typically contains abundant dissolved salts derived from return irrigation flow which has leached dissolved salts accumulated in soils from evaporation (Richardson, 1907). For example, ground water from a 22.5-foot- (7 m) deep well centered in section 15, T. 17 N., R. 2 E., Salt Lake Base Line and Meridian, had a specific conductance of 26,800 micromhos per centimeter at 25˚C on November 30, 1989 (Wilberg and Heilweil, 1995).

Table C3. *Quaternary alluvial springs, Sanpete Valley, Sanpete County, Utah (modified from Robinson, 1968).*

Location	Name	Geologic Unit	Yield (gallons per minute) e=estimated m=measured r=reported	Date of measurement	Specific conductance (micromhos/cm at 25°C)
(D-13-4) 2dda-S1	Spring Branch	Quaternary alluvium	270r 306m 270m	- 1-26-66 5-3-66	- 600 580
26d-S	Spring Branch	Quaternary alluvium	340e	9-30-66	-
(D-14-2) 11ddb-S1	Squaw Spring	Quaternary alluvium	17m	1-14-66	930
(D-14-4) 11ad-S	Lower Spring Creek (Mill Creek)	Quaternary alluvium	1,870m	1-25-66	630
23ca-S	Meiling Spring	Quaternary alluvium	150r	1936	810
(D-14-4) 34bbc-S1	Waldemar Springs	Quaternary alluvium	225m	10-14-66	510
(D-15-3) 4c-S	1st and 2nd Ditches	Quaternary alluvium	1,080r 1,600m 1,190m 965m	1-24-66 4-27-66 8-9-66 11-7-66	700 690 640 710
5dba-S1	Prestwich Spring	Quaternary alluvium	229m 301m 239m 211m	1-24-66 4-27-66 8-9-66 11-7-66	450 560 460 470
25ccb-S1	Unnamed	Quaternary alluvium	0.5e	11-28-66	1,300
(D-15-4) 8bb-S	Snake Springs	Quaternary alluvium	405r 818m 792m 832m 963m	- 1-25-66 5-5-66 8-4-66 11-9-66	- 640 610 620 590
29dcb-S1	Spring City Spring	Quaternary alluvium	22m	11-15-66	600
(D-16-3) 33ba-S	Justeson Springs	Quaternary alluvium	125e	1-21-67	1,700
(D-17-2) 27abc-S1	Unnamed	Quaternary alluvium	50e	1-5-67	750
(D-18-2) 2add-S1	Unnamed	Quaternary alluvium	418 248	1-27-66 4-27-66	1,000 800
(D-18-2) 2add-S1	Unnamed	Quaternary alluviu	180m 216m	8-3-66 11-4-66	810 840
3dad-S1	Barton Springs	Quaternary alluvium	300e	11-19-65	820
27cab-S1	Bown's Spring	Quaternary alluvium	100e	5-5-66	-
33bdd-S1	Funk's Spring	Quaternary alluvium	350e	8-24-65	680
(D-19-2) 3ab-S	Braithwaite Spring	Quaternary alluvium	110e	8-25-65	820
5ba-S	Olsen Springs	Quaternary alluvium	350-550r	8-19-65	1,200
5da-S	Pettyville Springs	Quaternary alluvium	450e	8-24-65	1,100
33acd-S1	Mayfield Spring	Quaternary alluvium	63r	1907	764
(D-20-2) 3aaa-S1	Unnamed	Quaternary alluvium	75e	7-13-65	620

Table C4. *Nitrate-as-nitrate concentration in ground water from water wells and springs in Sanpete Valley, Sanpete County, Utah (data from Robinson, 1968).*

Well or Spring location	Date of collection	Nitrate (as NO_3) mg/L
(D-13-5) 33ada-S1	8-29-57	0.4
(D-14-2) 2bab-S1	2-26-41	0.0
"	4-10-41	0.0
"	8-29-57	2.0
"	2-20-64	0.6
(D-14-2) 13aaa-1	5-55	2.4
"	12-4-57	3.3
"	7-3-58	2.7
(D-14-3) 7bbb-1	8-27-51	-
(D-14-3) 20cbb-1	5-18-65	5.7
(D-14-3) 33bcc-1	5-55	42
"	12-4-57	32
"	7-3-58	39
"	7-29-59	14
"	7-27-60	36
(D-14-4) 1abc-1	7-25-52	11
(D-14-4)12cdd-1	7-31-65	6.5
(D-14-4) 24bbb-1	6-29-65	17
(D-14-5) 16bdd-1	12-21-56	0.6
"	5-18-59	0.2
"	1-20-62	1.1
(D-15-2) 2ada-S1	5-7-41	0.0
(D-15-2) 12aad-1	4-30-65	0.3
(D-15-2) 26acb-S1	5-7-41	0.0
"	8-28-57	0.7
"	5-12-64	1.2
(D-15-3) 8cda-3	4-30-65	0.0
(D-15-3) 9ddc-1	9-21-55	8.2
(D-15-3) 25ccb-S1	11-2-51	0.3
(D-15-3) 26ccd-1	5-12-64	0.7
"	1-21-67	0.1
(D-15-3) 28aba-1	12-4-57	4.6
"	7-3-58	4.5
"	7-29-59	3.2
(D-15-3) 28aba	7-22-60	3.8
"	9-25-63	-

Table C4 *(continued)*

Well or Spring location	Date of collection	Nitrate (as NO_3) mg/L
(D-15-4) 2adb-1	8-20-52	5.7
(D-15-4) 4dda-1	6-29-65	17
(D-15-4) 8dcd-1	5-19-65	6.7
(D-15-4) 29dcb-S1	1-20-62	20
(D-15-4) 31dcc-1	4-29-65	5.4
(D-15-4) 32bab-1	11-15-66	7.8
(D-15-5) 22bbb-S1	2-20-64	0.5
(D-16-2) 35acd-2	7-21-66	15
(D-16-2) 36cbd-1	6-5-65	0.0
(D-16-3) 4aaa-1	11-2-51	6.1
“	5-55	5.7
(D-16-3) 4aaa-2	11-2-51	5.7
(D-16-3) 7abc-1	4-29-65	42
(D-16-3) 9bbb-1	4-29-65	0.2
(D-16-3) 15cda-1	6-4-65	26
(D-16-3) 21bbb-2	4-29-65	0.3
(D-16-3) 21cdb-2	4-29-65	21
(D-16-3) 24aba-1	7-30-65	0.0
(D-16-3) 33ba-S	1-20-62	6.2
(D-16-4) 13adb-S1	8-28-57	1.5
(D-17-2) 1cba-1	11-2-51	0.3
(D-17-2) 1cba-2	11-2-51	0.6
(D-17-2) 11dad-1	8-27-51	-
(D-17-2) 15dac-1	11-2-51	2.4
(D-17-2) 22ddc-3	4-28-65	2.1
(D-17-2) 35ada-1	7-3-58	4.0
“	7-29-59	2.1
“	7-27-60	0.2
(D-17-2) 35ada-1	7-26-61	-
“	9-25-63	-
(D-17-3) 6aad-1	4-28-65	2.0
(D-17-3) 6bcd-1	11-2-51	29
(D-17-3) 6dbb-3	5-55	43
(D-17-3) 19bcb-1	4-28-65	20
(D-17-3) 20dbb-1	8-28-57	21
(D-17-3) 30dbd-1	5-55	0.9
(D-17-4) 16dcd-S1	4-10-41	0.0

Table C4 *(continued)*

Well or Spring location	Date of collection	Nitrate (as NO_3) mg/L
(D-17-4) 16dcd-S1	8-28-57	2.0
(D-18-2) 10daa-1	4-27-65	15
(D-18-2) 12bab-1	4-30-62	7.4
"	7-20-65	20
(D-18-2) 13cad-S1	2-6-41	3.0
"	1-23-62	0.6
(D-18-2) 14aac-1	7-19-66	0.8
(D-18-2) 22add-1	4-27-65	2.5
(D-18-2) 23aac-S1	7-22-66	1.2
(D-18-2) 33abc-1	4-27-65	4.2
(D-18-2) 35cda-1	12-7-45	0.0
(D-18-4) 20bb-S	8-28-57	2.0
"	6-24-66	0.3
(D-19-2) 1dbc-S1	5-7-41	0.0
"	2-20-64	1.4
(D-19-2) 4dca-S1	9-8-50	0.7
"	8-27-57	0.1
"	6-18-64	0.2
(D-19-2) 8dcb-S1	5-7-55	41
(D-19-2) 9cbb-S1	11-2-51	42
(D-19-2) 17aad-1	4-27-65	19
(D-19-2) 20ddd-S1	8-28-57	23
(D-19-2) 32aac-1	7-27-65	38
(D-19-2) 33acd-S1	7-13-65	43

Table C5. *Nitrate-as-nitrogen concentration in ground water from water wells and springs in Sanpete Valley, Sanpete County, Utah (data from Wilberg and Heilweil, 1995).*

Well or Spring location	Date of collection	Nitrate (as N) mg/L
(D-14-2) 2bab-S1	08-22-89	0.250
(D-14-2) 12aaa-1	08-29-88	2.80
(D-14-3) 20aca-1	08-08-89	15.0
[1](D-15-3) 14bdb-1	07-05-89	<0.10
(D-15-4) 7dad-1	07-27-89	3.00
(D-16-2) 13dda-1	08-30-88	<0.10
(D-16-2) 35acd-1	08-08-89	3.10
(D-16-2) 36cbd-1	08-08-89	0.240
(D-16-3) 1bbb-2	06-07-89	4.10
(D-16-3) 4aaa-1	09-14-82	1.10
“	03-04-87	1.20
(D-16-3) 21cdb-2	09-01-88	3.40
[1](D-16-3) 26cbd-1	07-06-89	<0.10
[1](D-16-4) 18bac-2	07-05-89	6.30
(D-17-2) 14cca-1	11-30-88	<0.10
(D-17-2) 14cca-2	11-30-88	<0.10
(D-17-2) 14ccb-1	06-07-89	0.730
[1](D-17-3) 3dbd-1	07-24-89	<0.10
(D-17-3) 20acc-1	08-30-88	3.60
(D-18-2) 1daa-2	08-23-82	0.60
“	08-09-89	7.20
(D-18-2) 2cbb-S1	09-26-89	2.90
(D-18-2) 11bcc-2	07-28-88	4.00
(D-18-2) 23adb-S1	09-26-89	<0.10

[1]Completed in consolidated rock.

Nitrate, typically associated with human activities, also has been identified in ground water in Sanpete Valley. Nitrate concentrations in ground water have been analyzed and reported in two different ways in Sanpete Valley: nitrate as nitrogen and nitrate as nitrate. The values for nitrate as nitrate are much higher than the corresponding values for nitrate as nitrogen. The Utah ground-water quality (health) standard for nitrate as nitrogen is 10 mg/L, and 45 mg/L for nitrate as nitrate.

Robinson (1968, p. 43-44) reported nitrate-as-nitrate concentrations ranging from 0.0 to 43 mg/L for wells in Sanpete Valley (table C4). Although several samples exceeded 40 mg/L nitrate as nitrate, no water from wells exceeded the ground-water quality standard for nitrate-as-nitrate (Robinson, 1971). Wilberg and Heilweil (1995, p. 120-121) reported nitrate-as-nitrogen concentrations in Sanpete Valley ranging from less than 0.100 to 15.0 mg/L (table C5), with one value exceeding the ground-water quality standard. Horns (1995) summarized historical nitrate data, including unpublished data collected by Utah State University, the city of Moroni, the Moroni Feed Company, and the Utah Division of Drinking Water, for ground water in the valley-fill aquifer in northern Sanpete Valley (table C6).

Table C6. *Partial list of nitrate-as-nitrogen concentration in ground water from wells in northern Sanpete Valley (modified from Horns, 1995).*

Well Location	Data Source*	Year of Data	Nitrate (as N) (mg/L)
(D-14-3)			
33bcc	USGS (1968)	1955	42.0
“	“	1957	32.0
“	“	1958	39.0
“	“	1959	14.0
“	“	1960	36.0
33ccc	USU	1993	1.4
(D-15-2)			
12aad	USGS (1968)	1965	0.3
(D-15-3)			
3dda	USU	1993	9.7
8cda	USGS (1968)	1965	0.00
9ddc	USGS (1968)	1955	8.2
9dcc	UDDW	1993	0.9
10acd	USU	1993	8.1
10dad	USU	1993	18.6
14bdb	USGS	1989	0
15cac	USU	1993	9.4
16bcd	UDDW	1993	1.0
16abb	UDDW	1993	2.0
16aac	USU	1993	51.0
26ccd	USGS (1968)	1964	0.7
“	“	1967	0.1
28aba	USGS (1968)	1957	4.6
“	“	1958	4.5
“	“	1959	3.2
“	“	1960	3.8
(D-15-4)			
2adb	USGS (1968)	1952	5.7
4dda	USGS (1968)	1965	17.0
7dad	USGS	1989	3.0
8dcd	USGS (1968)	1965	6.7
29dcd	USGS (1968)	1962	20.0
31dcc	USGS (1968)	1965	5.4
32bab	USGS (1968)	1966	7.8

*USGS (1968): From Robinson, U.S. Geological Survey (1968).
USGS: Unpublished data from the U.S. Geological Survey.
USU: Unpublished data from Utah State University.
UDDW: Unpublished data from the Utah Division of Drinking Water.

APPENDIX D

POTENTIAL SOURCES OF GROUND-WATER QUALITY DEGRADATION

Introduction

The type and amount of dissolved constituents determine the beneficial use of water. Ground-water quality standards for drinking water are provided in table 1. Degradation in ground-water quality may be due to either natural sources or contamination associated with human activities. Many constituents dissolved in water are derived from geologic materials such as rock or sediment. As discussed below, natural sources of nitrogen which may be oxidized to nitrate do occur, but are not considered common. Thomas and Taylor (1946) noted that nitrate concentrations more than a few mg/L in shallow ground water is considered an indication of water-quality degradation typically associated with human-related activities; water-quality data collected from 124,000 water wells nationwide (figure D1) support the designation of 3 mg/L as a division between human- and natural-nitrate influences (Madison and Brunett, 1985). In general, elevated nitrate levels in ground water are primarily obtained from wells less than 100 feet (30 m) deep (Madison and Brunett, 1985), and an inverse relationship exists between well depth and nitrate concentration (Spruill, 1983).

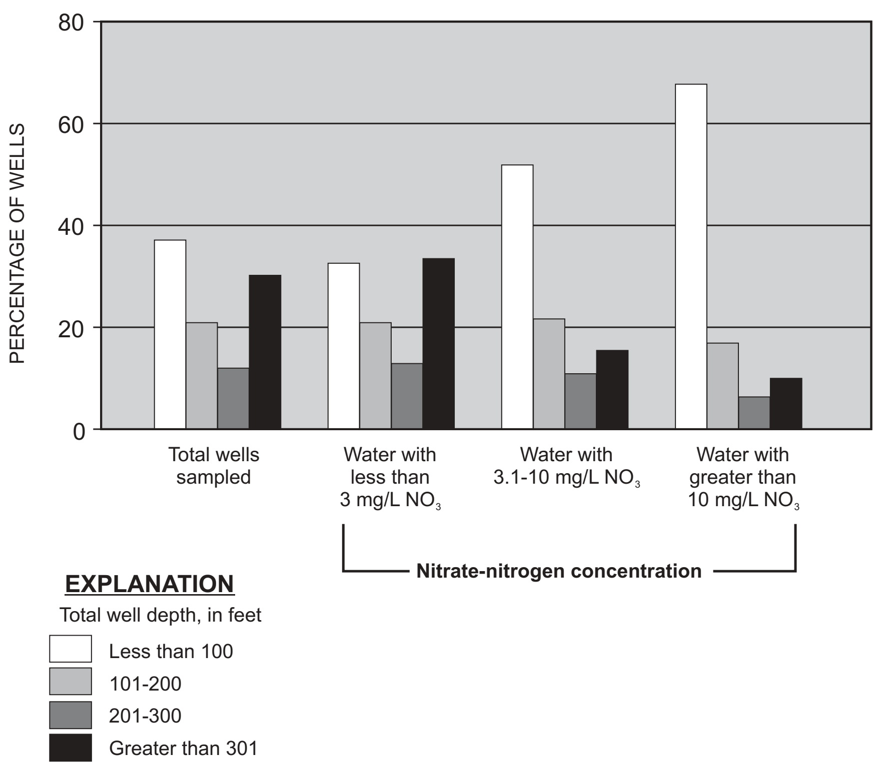

Figure D1. *Distribution of nitrate concentrations (milligrams per liter) in well water with well depth. About 124,000 wells were included in the analysis (from Madison and Brunett, 1985).*

Natural Sources of Water-Quality Degradation

Dissolved Solids

The ultimate source of most chemical constituents dissolved in water is the mineral assemblage in rocks at or near the land surface; other important factors determining the composition of water passing over or through rock masses and unconsolidated deposits include, but are not limited to, the purity and crystal size of minerals, rock and soil texture and porosity, regional structure, the degree of fracturing, the length of previous exposure time, and rock temperatures (Hem, 1985). The mineral assemblage in the rock unit determines the type of dissolved constituents. In mining areas, dissolved metals, arsenic, and sulfide (which readily oxidizes to sulfate) can contribute to water-quality degradation. Rock units rich in evaporite deposits, sulfates, and chlorides can degrade water quality. Water from carbonate rock units can be hard from dissolved calcium and magnesium. Silica-rich rock units, such as volcanic rocks, contribute negligible dissolved material to ground water. In general, total-dissolved-solids concentrations increase with increased residence time and longer ground-water flow paths. Climate and biochemical factors play secondary roles in determining the nature and distribution of dissolved solids in ground water (Hem, 1985).

Nitrate

Natural sources of nitrogen contribute, to some extent, nitrate concentrations in ground water; these natural sources include atmospheric, biologic, and geologic components. Ground water with less than 0.2 mg/L nitrate is assumed to represent natural background concentrations; ground water with nitrate concentrations between 0.21 and 3.0 mg/L is considered transitional, and may or may not represent human influence (Madison and Brunett, 1985).

Atmospheric nitrogen: Nitrogen oxides are present in the atmosphere and can undergo various chemical reactions that produce hydrogen ions, eventually converting the nitrogen to nitrate or ammonia, reducing the pH of precipitation (Hem, 1985). Concentrations of nitrate in rainfall typically range from 0.1 to 0.7 mg/L (National Academy of Sciences, 1978). In Smith Valley, Colorado, during 1986-93, the mean annual average-precipitation-weighted concentration of ammonia was 0.30 mg/L and of nitrate was 0.76 mg/L (Colorado State University at Fort Collins, National Atmospheric Deposition Program/National Trends Network Coordination Office, written communication, in Seiler, 1996). Seiler (1996) estimated the total-nitrogen contribution from precipitation per year in Lemmon Valley, Nevada is 0.91 kilograms (2 lbs). Data collected from rainfall in the United States indicate, in general, that nitrogen concentrations are lower in coastal areas than inland (Junge, 1958, in Feth, 1966). Not all nitrogen introduced by rainfall is natural in origin. Human activities contribute approximately 50 percent of the fixed nitrogen from rainfall, the combustion of fossil fuels being the largest source of this anthropogenic nitrogen (National Academy of Sciences, 1978).

Some portion of nitrogen in rainfall is removed through volatilization, used by plants, or denitrified in saturated soils rich in organic matter (Seiler, 1996); Walker and others (1973) estimated 12.5 to 25 percent of the nitrogen in precipitation reaches ground water.

Biologic nitrogen: Natural sources of biologic nitrogen include decay of organic material (primarily from plant remains) and animal excrement. The accumulation of natural nitrogen in caves from bat guano or in coastal breeding grounds from seabirds is well known, and these deposits are sources of commercial nitrogen fertilizer; however, the extent to which these sources contribute to nitrate in ground water has not been well documented (Madison and Brunett, 1985). Water pools in Carlsbad Caverns, New Mexico, near cave areas frequented by bats have yielded water samples having more than 1,000 mg/L of nitrate (Hem, 1985).

Decay of natural organic material in the subsurface also can contribute nitrogen to ground water (Seiler, 1996). Native vegetation that had been destroyed by dryland farming was shown by Kreitler and Jones (1975) to have contributed high concentrations of nitrate to ground water in west-central Texas; the average nitrate concentration (nitrate reported as nitrate) for 230 sampled wells was 250 mg/L, and the highest nitrate concentration exceeded 3,000 mg/L. Patt and Hess (1976) identified naturally occurring, buried plant material as a possible source of nitrate-related water-quality degradation in domestic wells near Las Vegas, Nevada.

Geologic nitrogen: Many investigators have recognized the contribution of bedrock nitrogen to nitrate concentrations in water (Mansfield and Boardman, 1932; Gulbrandsen, 1974; Power and others, 1974; Boyce and others, 1976; Holloway and others, 1998; Holloway and Dahlgren, 1999). The following is a summary of types of rocks that have contributed nitrogen to nitrate concentrations in ground and surface water. Many of the rock types described below are also present in Sanpete Valley including volcanic and sedimentary rocks (for example, sandstone, limestone, shale, coal-rich deposits, evaporites, and playa-type deposits), and alluvial sediments. A more detailed discussion regarding natural sources of nitrate is presented in a special evaluation of potential sources of nitrate contamination in ground water in Cedar Valley, Iron County, Utah, by Lowe and Wallace (2001).

Release of nitrogen through weathering of nitrogen-bearing rock can potentially affect the quality of water and soil (Holloway and others, 1998). The term "geologic nitrogen" has been used to describe the source of high-nitrogen soils on alluvial fans in the San Joaquin Valley of California (Sullivan and others, 1979; Strathouse and others, 1980), and sedimentary rocks in Nebraska (Boyce and others, 1976). Holloway and others (1998) analyzed rocks in the Mokelumne River watershed, California, to determine if bedrock could be a source of stream-water nitrate and showed that metasedimentary rocks containing appreciable concentrations of nitrogen contributed a large amount of nitrate to surface waters.

Sedimentary rocks that form in an organic-rich depositional environment can include nitrogen as residual organic matter or as ammonium minerals (Holloway and others, 1998). Ammonium concentrations in rock associated with hydrocarbons are a function of fluid migration and hydrocarbon maturation (Williams and others, 1989; Williams and others, 1993). The accumulation of ammonium in illite above and below coal seams in the Cummock Formation of South Carolina indicates that nitrogen is transported from the organic matter in the coal seam to mineral sites where ammonium substitutes for potassium (Krohn and others, 1993).

Natural nitrate is also associated with sediments typical of arid environments such as playa-lake, alluvial-fan, and braided-stream deposits, primarily associated with atmospheric nitrogen. Rock-salt crusts in Chilean playas contain soda niter (Stoertz and Ericksen, 1974) associated with oxidized ammonium salts that were subsequently leached and mobilized as nitrate in ground water. High nitrate concentrations in ground water from wells in Paradise Valley, Arizona, are partly attributed to natural sources of nitrate, possibly from ammonium chloride that was produced and trapped in volcanic rocks, and with subsequent weathering, leaching, and oxidization, eventually was transported as nitrate by ancient streams (Silver and Fielden, 1980). Nitrate exists as water-soluble salts in zones below leached soils in evaporative playa environments in southeastern California, and is associated with Tertiary playa deposits and beds of saline and gypsiferous shale, sandstone, and limestone (Noble, 1931).

Ground-Water Contamination from Agricultural Activities

Many agricultural activities can potentially degrade water-quality, including irrigation (especially flood irrigation), pesticide application, fertilizer application, raising of nitrogen-fixing crops, livestock grazing, and feed-lot operations. Increased total-dissolved-solids concentrations in ground water is the principal concern related to irrigation practices. Ground-water contamination associated with pesticides is relatively uncommon in Utah; during calendar year 2000, no pesticides were detected in ground water in 318 samples collected from wells and springs in Utah and analyzed by the Utah Department of Agriculture and Food (Ivan Sanderson, Utah Department of Agriculture and Food, verbal communication, November 30, 2000). Nitrate and other forms of nitrogen are the principal contaminants of concern with respect to fertilizer application, some crop types, grazing, and feed-lot operations.

Irrigation Practices

The role of irrigation for crop-production expansion increased during the last century in the United States (Feth, 1966). Shallow wells in areas where flood irrigation is common typically have high total-dissolved-solids concentrations. The dissolved solids are derived from naturally occurring shallow ground water and from irrigation. Excess irrigation and return-irrigation water leach soil in valley lowlands where ground water is within the zone of capillary action and the accompanying “alkali” salt-rich soil (Richardson, 1907). These dissolved salts in the soil are concentrated by flood-irrigation processes as near-land-surface water evaporates (Pipkin, 1994). Reducing rates of flood irrigation, in some areas, can produce additional salts in irrigation return flows as the quantity of salts removed by periodic leaching decreases (National Academy of Sciences, 1978). To leach out these unwanted salts and maintain soil salinity within crop tolerance, the amount of water applied must exceed plant requirements (Feth, 1966).

Leaching of soil by sprinkler irrigation water occurs at a much lower rate. In Panguitch Valley, Sevier County, Utah, Thiros and Brothers (1993) demonstrated that sprinkler irrigation increased moisture content only in the upper 1 to 3 feet (0.3-0.9 m) of the soil zone. Between 1975 and 1989, the percentage of irrigated land using sprinkler irrigation methods increased from 10 to 50 percent (Wilberg and Heilweil, 1995).

Agricultural Fertilizer

Nationwide, the largest single source of anthropogenic nitrogen is fertilizer, due to an increase in chemical fertilizer application occurring since the end of World War II (National Academy of Sciences, 1978); figure D2 shows fertilizer sales between 1960 and 1975. In Utah, 88,000 tons of fertilizers were used during the 1969-70 period (Geraghty and others, 1973, plate 54). The amount of fertilizer typically applied varies with crop type (table D1). The amount of nitrogen from fertilizers depends on: (1) the amount and type of fertilizer applied, (2) the pH of the soil to which it is applied, (3) the air temperature at the time of application, and (4) the amount of water applied after the fertilizer application (Seiler, 1996). Fertilizer-use efficiency depends more on crop-production management than on fertilizer-application rates; farms using large quantities of fertilizer to optimize crop yield may be using the nutrients more efficiently and producing less leachable nitrogen than farms applying less fertilizer to produce average yields (1971 Illinois Pollution Control Board in National Academy of Sciences, 1978). However, excess fertilizer application is generally avoided, based on econom-

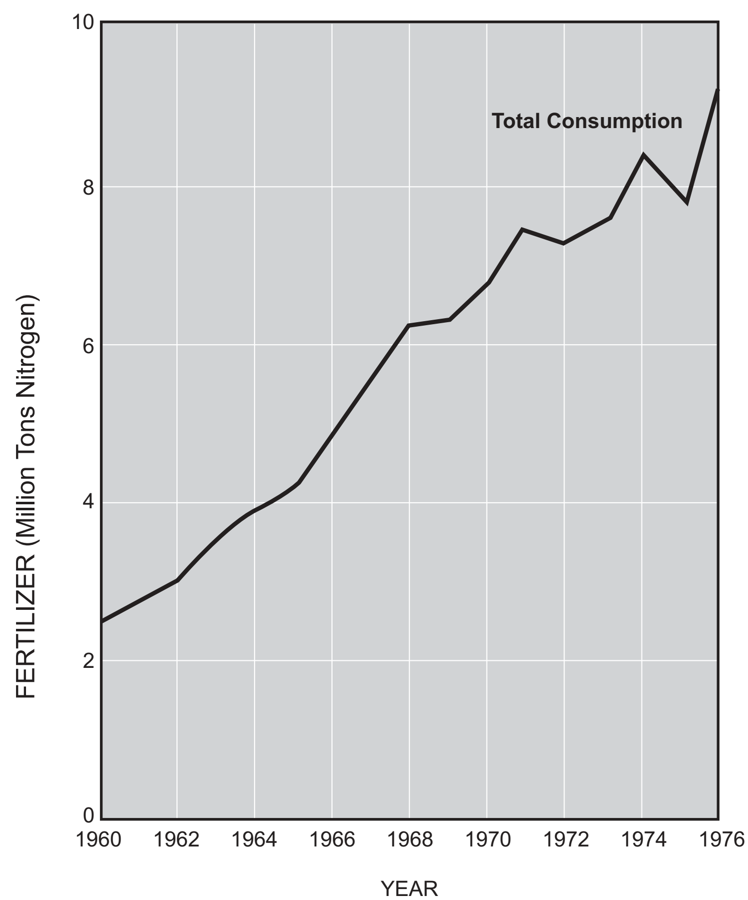

Figure D2. *Consumption of nitrogen fertilizer in the United States, 1960-1976 (modified from National Academy of Sciences, 1978).*

Table D1. Average nitrogen-fertilizer application rates on selected crops in California for 1973 (modified from National Academy of Sciences, 1978).

Crop	Common Rate of Application, kg N/ha
Barley (irrigated)	89
Corn	191
Cotton	122
Rice	96
Wheat (irrigated)	117
Alfalfa	22
Pasture (irrigated)	71
Peaches	145
Prunes	107
Wine Grapes	59
Asparagus	159
Carrots	135
Lettuce	178
Melons (cantaloupe)	106
Tomatoes	159
Turf	224

ics alone. The 1971 Illinois Pollution Control Board reported crop-price increases from 1971 to 1975 (2.2 times for corn) accompanied by nitrogen fertilizer increases of a factor of 3.4, and concluded that economics alone would demand that farmers carefully monitor nitrogen fertilizer application rates.

The role of air temperature and soil pH varies in nitrification/denitrification processes associated with fertilizers. Both parameters are inherent properties, independent of external control by fertilizer users. Certain pH and temperature conditions can facilitate nutrient uptake, but can also impede nutrient uptake of nitrogen, and ultimately contribute to water-quality degradation. For example, both nitrification and denitrification rates are higher during warm temperatures than cold temperatures because cold temperatures slow the functioning of biologic organisms important to both processes (National Academy of Sciences, 1978). Prevailing basic or acidic conditions also can impact the nitrification/denitrification process. Under certain soil/liquid pH conditions, ammonia gas is released into the atmosphere. For example, under neutral or acidic conditions, nitrogen is present as NH_4^+, and with increasingly basic conditions is transformed to ammonia which can be released as N gas to the atmosphere (Canter, 1997). When the redox potential of the ground water declines, denitrification of nitrate can also occur (Canter, 1997). Biologic denitrification can occur in the presence of organic carbon in ground water. In this process, microorganisms utilize nitrate as an electron acceptor, and can eventually be reduced to nitrogen gas (Canter, 1997). Fertilizing intensity can also affect the pH of the soil in terms of oxidation potential. If the amount of fertilizer applied exceeds that required by the crops, nitrate concentrations may increase in ground water. As nitrate becomes available through oxidation, it can be leached from the root zone (Canter, 1997).

Nitrogen fertilizer is either used by plants, lost through denitrification (biological reduction of nitrate to nitrogen gas), leached into the ground-water system, or immobilized in soil materials (National Academy of Sciences, 1978, p. 239). Westerman and others (1972) estimated 22 to 25 percent of fertilizer applied to test plots in Iowa during the spring of 1966 was unaccounted for at the end of the crop cycle and attributed this loss primarily to denitrification. Although denitrification of fertilizer may account for nitrogen not used by crops, leaching of nitrogen-based fertilizer to ground water does occur, and the extent to which this contributes to ground-water quality degradation depends partly on irrigation practices.

In non-irrigated lands (dry farms), leaching of nitrate in the upper soil zones generally occurs during spring snowmelt. Nitrogen fertilizers within the upper few feet of soil are incorporated into organic matter, stabilize, and become less susceptible to leaching (Allen and others, 1973). Additionally, nitrate in soils in non-irrigated areas migrate through the soil profile at rates ideal for denitrification (Pratt and others, 1972). In general, nitrogen from fertilizers does not pollute ground water beneath non-irrigated farms, whereas poor farm-irrigation management promotes nitrogen leaching into the ground-water system (Sommerfeldt and Smith, 1973).

Muir and others (1973) reported that the intensity of irrigation, particularly in areas underlain by coarse-grained materials, controls nitrogen contamination of ground water. Irrigation water leaches nitrate from soil and into the ground-water system through the same processes discussed for leaching of "alkali" salts discussed above. Ground water under heavily fertilized, irrigated crop lands can contain high concentrations of nitrate (National Academy of Sciences, 1978). Adriano and others (1972) report nitrate-as-nitrogen concentrations 10 to 50 feet (3-15 m) below row crops in the Santa Ana Basin of California range from 36 to 122 mg/L; water from wells completed in deeper aquifers below these sites currently average only 5.8 mg/L nitrate as nitrogen, but some wells in the basin exceed 20 mg/L nitrate as nitrogen. Most data based on ground-water studies below California crop lands indicate nitrate levels are typically about 25 to 30 mg/L nitrate as nitrogen (National Academy of Sciences, 1978). However, more efficient water use through decreasing irrigation rates is a viable method to reduce the amount of nitrate leached into the ground water and thus lost as fertilizer nitrogen (National Academy of Sciences, 1978).

Nitrogen-Fixing Crops

Some plants, principally legumes, have the ability to fix nitrogen into the soil; this nitrogen could subsequently be leached into the ground-water system. Table D2 lists the legume types and summarizes their average nitrogen fixation rates. Alfalfa is the most efficient of the legumes with respect to nitrogen fixation (table D2). The actual fixation of atmospheric nitrogen is by bacteria of the genus *Rhizobium*, symbiotic with the legumes. Although it is prudent to provide some nitrogen fertilizer to young legumes to keep them supplied with nutrients until the Rhizobia are stabilized on their roots (Tisdale and Nelson, 1975), additional fertilization application is ineffectual. Nitrogen fixation by legumes is at a maximum only when the level of nitrogen available in the soil is at a minimum, and large or continued applications of nitrogen cause a reduction in the activity of the Rhizobia (Tisdale and Nelson, 1975).

Animal Grazing and Feed-Lot Operations

Water-quality degradation associated with livestock operations is related to the intensity of operation in terms of animal density. Dispersed grazing on rangelands presents no obvious environmental problems, but a trend of increasing animal-production efficiency by high-density confinement of poultry, hogs, and cattle exists, along with the concentrated accumulation of animal wastes (National Academy of Sciences, 1978). Egg-laying facilities may house up to one million confined birds, and pork operations which house animals from birth to finishing are becoming common (Nye, 1973).

From a water-quality standpoint, manure is probably the most important component of animal waste produced from feed-lot operations. Manure is a combination of feces, urine, bedding litter, and feed wastage (Brady, 1974). The chemical composition of manure varies depending on: (1) animal species, (2) age and condition of the animals, (3) nature and amount of litter, and (4) handling and storage of the litter before it is spread on the land or otherwise disposed (Brady, 1974). Table D3 summarizes moisture and nutrient content in manure from common farm animals. The average cow, horse, and pig excretes 156, 128, and 150 pounds of nitrogen per year, respectively (Van Vuren, 1949); the waste produced by one horse over a year contains as much nitrogen as the domestic sewage produced by a family of four for the same period (Hantzsche and Finnemore, 1992).

Besides manual waste removal (from cleaning processes) and natural removal by storm runoff, four other possible fates exists for nitrogen in manure: (1) accumulation in the soil, (2) percolation into unconsolidated deposits below the soil zone as ammonium, nitrate, and soluble organic compounds, (3) denitrification, and/or (4) atmospheric loss as ammonia and volatile bases (National Academy of Sciences, 1978). Under warm, moist conditions, urea hydrolyzes rapidly to form NH_3 and CO_2; this process can account for 25 to 90 percent of the nitrogen in urine (Stewart, 1970), or approach 50 percent of the nitrogen in urine and feces combined (Adriano and others, 1974). Snow cover prevents volatilization of nitrogen as ammonia (Lauer and others, 1976), and only 30 percent of nitrogen in manure applied to the land surface is lost to the atmosphere when the air temperature is 50˚F (10˚C) (Vinten and Smith, 1993). Low infiltration rates of active feed lots from hydrophilic substances in

Table D2. *Average fixation of nitrogen by legumes (modified from Tisdale and Nelson, 1975).*

Legume	**Nitrogen Fixed (pounds per acre)**	**Legume**	**Nitrogen Fixed (pounds per acre)**
Alfalfa	194	Lespedezas (annual)	85
Ladino clover	179	Vetch	80
Sweet clover	119	Peas	72
Red clover	114	Soybeans	100
Kudzu	107	Winter Peas	50
White clover	103	Peanuts	42
Cowpeas	90	Beans	40

Table D3. *Moisture and nutrient content of manure from farm animals (modified from Brady 1974).*

Animal	**Feces/Urine**	**H_2O (%)**	**Manure (pounds per ton)**		
			N	**P_2O_5**	**K_2O**
Dairy Cattle	80:20	85	10.0	2.7	7.5
Feeder Cattle	80:20	85	11.9	4.7	7.1
Poultry	100:0	62	29.9	14.3	7.0
Swine	60:40	85	12.9	7.1	10.9
Sheep	67:33	66	23.0	7.0	21.7
Horse	80:20	66	14.9	4.5	13.2

manure, and soil compaction caused by hoof action also tends to promote volatilization (Mielke and others, 1974). Nitrogen transferred into the atmosphere due to volatilization as ammonia is commonly transferred by wind away from the immediate vicinity of the feed lot, sometimes creating unpleasant odors, but ultimately contributing to nitrogen loading of nearby areas, especially lakes (Hutchinson and Viets, 1969).

Major controls on ground-water contamination from animal feed lots and their associated treatment and disposal facilities include: (1) runoff and infiltration from the feed lots themselves, (2) runoff and infiltration from waste products collected and disposed on land, and (3) seepage and infiltration through the bottoms of waste lagoons (Miller, 1980). Based on analysis of water from more than 5,000 wells and springs in Missouri, Keller and Smith (1967) reported 42 percent of the ground-water sources yielded samples containing more than 5 mg/L nitrate as nitrogen and reported the dominant source as nitrogenous waste from livestock feed lots. More than 20 percent of samples from 800 wells in Sussex County, Delaware, where millions of chickens are raised annually, exceeded the drinking-water standard of 10 mg/L nitrate as nitrogen; the average nitrate-as-nitrogen concentration in ground water sampled at chicken farms was 14 mg/L (Robertson, 1979).

Ground-Water Contamination from Septic-Tank Systems

Though commonly treated as non-point sources of ground-water quality degradation, septic-tank systems are potential point sources of pollution, because each septic-tank system has an associated discrete plume of wastewater (Harman and others, 1996; Canter, 1997). Localized contamination, such as effluent from a disposal system entering a nearby well, can occur in almost any hydrogeologic setting (Madison and Brunett, 1985).

Harman and others (1996) delineated a plume of effluent in an unconfined sand aquifer below a septic system servicing a school in Ontario, Canada. The septic system produced a 50-foot-wide (15 m) plume core 360 feet (110 m) downgradient from the septic-system tile bed with nitrate-as-nitrogen concentrations ranging from 20 to 120 mg/L (Harman and others, 1996). Harman and others (1996) estimated the ground-water flow velocity at the site to be about 330 feet (100 m) per year; thus the delineated plume represents only about 1 year of effluent loading. This case study shows that the placement of septic-tank systems with respect to water wells and springs, for example, should be considered in addition to overall density and lot size.

In urban or suburban areas where high densities of individual septic-tank systems are used, they contribute large quantities of wastes and have the potential to contaminate large parts of water-supply aquifers (Madison and Brunett, 1985). Wastewater from septic-tank systems contains many constituents which can cause water-quality degradation (table 14).

Pathogens

As the effluent from a septic tank soil-absorption system leaves the drain field and percolates into the underlying soil, it can have high concentrations of pathogens, such as viruses and bacteria. Organisms such as bacteria can be mechanically filtered by fine-grained soils and are typically removed after traveling a relatively short distance in the unsaturated zone. However, in coarse-grained soils, or soils containing preferential flow paths such as cracks, worm burrows, or root holes, these pathogens can reach the water table. Pathogens can travel up to 40 feet (12 m) in the unsaturated zone in some soils (Franks, 1972). Some viruses can survive up to 250 days (U.S. Environmental Protection Agency, 1987), which is the minimum ground-water travel time for public water-supply wells or springs to be separated from potential biological contamination sources.

Household and Industrial Chemicals

Many household and industrial chemicals (table 14) are commonly disposed of through septic systems and, unless they volatilize easily, are not remediated by percolation through soils in the unsaturated zone. Contamination from these chemicals can be minimized by reducing their disposal via septic-tank systems, maximizing the potential for dilution of household and industrial chemicals that do reach ground water (Lowe and Wallace, 1999).

Phosphate

Phosphate, typically derived from organic material and some detergents, is discharged from septic-tank systems (Fetter, 1980). While phosphate (and phosphorus) causes eutrophication (increases in nutrient content and consequent oxygen deficiency) of surface waters (Fetter, 1980), it is generally not associated with water-quality degradation from septic-tank systems (Lowe and Wallace, 1999). Phosphates are removed from septic-tank system effluent by adsorption onto fine-grained soil particles and by precipitation with calcium and iron (Fetter, 1980). In most soils, complete removal of phosphate from septic-tank effluent is common (Franks, 1972).

Nitrate

Ammonia and organic nitrogen are commonly present in effluent from septic-tank systems (table 14), mostly from urine. Unlike animal wastes in feed-lot operations, waste in septic-tank systems is generally not exposed to the atmosphere, temperature is low, moisture is high, and air movement is inhibited; these conditions minimize ammonia volatilization in some septic tanks and drain fields (Wells and Krothe, 1989; Aravena and others, 1993). Although individual humans produce less nitrogen than individual farm animals, more of the nitrogen produced by animals is lost to the atmosphere before reaching ground water (Seiler, 1996).

Typically, almost all ammonia is converted into nitrate before leaving the septic tank soil-absorption system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, negligible attenuation takes place as it travels farther through the soil (Franks, 1972). Once in ground water, nitrate becomes mobile and can persist in the environment for long periods. Areas having high densities of septic-tank systems risk elevated nitrate concentrations reaching unacceptable levels. In the early phases of ground-water quality degradation associated with septic-tank systems, nitrate is likely to be the only pollutant detected (Deese, 1986). Regional nitrate contamination from septic-tank discharge has been documented on Long Island, New York, where many densely populated areas without sewer systems exist (Fetter, 1980).

A typical single-family septic-tank system discharges about 400 gallons (1,500 L) of effluent per day containing nitrate concentrations ranging from 30 to 80 mg/L (Hansen, Allen, and Luce, Inc., 1994). The U.S. Environmental Protection Agency maximum contaminant level for drinking water (Utah ground-water quality standard) for nitrate is 10 mg/L. Therefore, distances between septic tank soil-absorption system drain fields and sources of culinary water must be sufficient for dilution of nitrate in the effluent to levels below the ground-water quality standard.

Other Sources

Dynamite and other explosives contain nitrogen which can contribute to the degradation of ground-water quality. Van Denburgh and others (1993) documented nitrogen contamination at a Nevada facility which processed munitions. Mining activities can cause concentrations of sulfide, dissolved metals, and, if cyanide or nitric acids are used in ore processing, nitrogen. Industrial manufacturing can produce various potential ground-water contaminants; the production of ammonia, ammonium nitrate fertilizers, and nitric acid are sources of potential nitrogen contamination (Davis, 1973). We did not identify any of these activities in Sanpete Valley. Landfills and community sanitary sewage treatment plants are also potential sources of water-quality degradation, including nitrogen compounds.