U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
UTAH DEPARTMENT OF ENVIRONMENTAL QUALITY
Division of Water Quality

WATER-RESOURCES INVESTIGATIONS REPORT 92–4160
1993

INTRODUCTION

Washington County is in the southwest corner of Utah (fig. 1). From 1980 to 1990, the county's population increased by more than 86 percent, from about 26,000 to more than 48,000 (Utah State Data Center, 1991). Water availability is an important factor in supporting this growth. Annual precipitation, although as much as 30 inches in the mountains in the northern part of the county, is less than 10 inches in the southern part, where most of the population lives.

The Virgin River flows across Washington County from northeast to southwest into Arizona and then Nevada. The Virgin River and its tributaries provide surface water for irrigation of orchards and other agricultural produce. The main source of water for human consumption, however, is ground water from the Navajo Sandstone of Jurassic age. The part of the Navajo Sandstone that contains ground water is known as the Navajo aquifer and is the main focus of this report.

The study area for this report represents only part of Washington County. The Navajo aquifer is divided into two parts by a natural hydrologic boundary — the Hurricane Fault. The west side of the fault has been sufficiently downthrown (more than 2,000 feet)(Gregory, 1950, p. 144) to hydrologically isolate the Navajo aquifer on the west side of the county from that on the east side. The area investigated includes only that part of Washington County west of the Hurricane Fault.

The preservation of public water supplies is one of the primary concerns of the Utah Department of Environmental Quality. In the late 1980s the Department's Division of Water Quality began a series of investigations to define the character of the State's principal aquifers used for public water supplies. The objectives were to describe the physical extent of the aquifers, the areas where the aquifers are recharged, and the baseline quality of water contained in these aquifers. Knowing where the aquifer is recharged and the quality of the water is useful in designing ways to protect ground water from contamination. This report, prepared by the U.S. Geological Survey in cooperation with the Utah Department of Environmental Quality, Division of Water Quality, is the fourth report in this series of investigations.

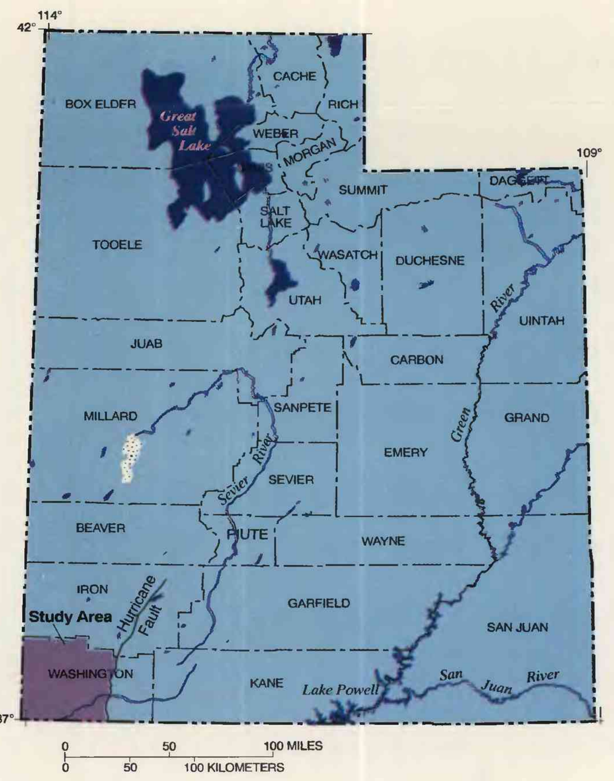

Figure 1. Location of Washington County, Utah, and study area.

Purpose and Scope

The purpose of this report is to (1) describe the lateral extent of the Navajo aquifer, (2) define the recharge areas of the Navajo aquifer and their relative importance, and (3) describe the general quality of the ground water in the Navajo aquifer. The information presented in this report was limited by time and funding. Extensive field investigation to determine rates of recharge was not possible, and not all factors that affect the recharge potential of different areas could be considered in detail. Analyses of ground-water samples collected previously and of eight samples collected during this investigation are used to describe the baseline quality of ground water in the Navajo aquifer.

Acknowledgments

The water-sample analyses done by the staff of Utah State Health Laboratory were greatly appreciated. Special thanks to William Duncan and Kenneth H. Bousfield of the Department of Environmental Quality, who collected the water samples and obtained water-quality data from the State's computer data base. Recognition and thanks also are extended to all the well and property owners who allowed access to their wells and springs for sampling.

Conversion Factors, Vertical Datum, and Abbreviated Water-Quality Units

Multiply	By	To obtain
foot	0.3048	meter
inch	2.54	centimeter
square mile	2.59	square kilometer

Water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32.$$

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

Chemical concentration and water temperature are reported only in metric units. Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is reported in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Radioactivity is expressed in picocuries per liter (pCi/L), which is the quantity of radioactive decay producing 2.2 disintegrations per minute in a unit volume (liter) of water.

Numbering System for Hydrologic-Data Sites

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating a well, spring, or other data-collection site, describes its position in the land net. The land survey divides the State into four quadrants separated by the Salt Lake Base Line and Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range, in that order, follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three lowercase letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section – generally 10 acres for regular sections[1]. The letters a, b, c, and d indicate respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well, spring, or miscellaneous site within the 10-acre tract. The letter S preceding the serial number designates a spring. Thus, (C-42-14)12dda-1 designates the first well constructed or visited in the northeast 1/4, southeast 1/4, southeast 1/4, section 12, T. 42 S., R. 14 W. (fig. 2). The number (C-41-16)34bda-S1 designates a spring in the northeast 1/4, southeast 1/4, northwest 1/4, section 34, T. 41 S., R. 16 W.

[1] Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

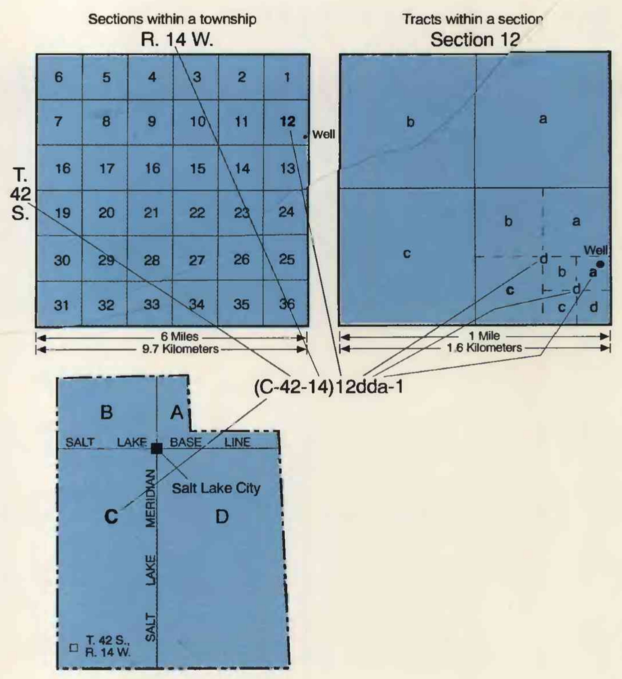

Figure 2. Numbering system used in this report for hydrologic-data sites.

HYDROLOGIC SYSTEM

A description of ground-water recharge, movement, and discharge in Washington County, Utah, is provided by Cordova, Sandberg, and McConkie (1972, p. 8), by Cordova (1978, p. 11), and by Clyde (1987, p. 19-28). In general, precipitation infiltrates downward through the Navajo Sandstone in outcrop areas and in areas where the Navajo Sandstone is overlain by younger formations, until it reaches the saturated part of the formation — the aquifer. Ground water in older formations east of the Hurricane Fault also moves as subsurface flow westward into the Navajo aquifer in the southeast part of the study area. Perennial and intermittent streams lose water to the aquifer as they traverse the Navajo Sandstone and the unconsolidated sediments and basalt flows that overlie the Navajo Sandstone. The rate of recharge from these sources has not been determined. In outcrop areas, open fractures are the main avenue of downward movement of water.

Contours mapped from water-level measurements of wells indicate that ground water in the Navajo aquifer north of St. George moves from the mountains southward toward the Virgin and Santa Clara River valleys. Ground water in the Navajo aquifer south of Hurricane, Utah, moves westward from the Hurricane Fault toward the Virgin River. Ground water in the Navajo aquifer south of Gunlock, Utah, moves southeastward toward the Santa Clara River and the Gunlock public-supply wells.

Ground water discharges naturally from the Navajo aquifer from springs, into streams, downward into the underlying Kayenta Formation, and through evapotranspiration by phreatophytes. Water also is being pumped out of the aquifer from wells. The large number of springs at the southern extent of the aquifer north of St. George indicates that ground water is probably moving southward through the aquifer, and that vertical movement down into the Kayenta Formation is slower than horizontal movement through the Navajo aquifer.

EXTENT OF THE NAVAJO AQUIFER AND RECHARGE AREA

The extent of the Navajo aquifer is assumed to correspond, relatively closely, to the extent of the Navajo Sandstone. Geologic maps show the southern erosional limit of the Navajo Sandstone and where it crops out (Hintze, 1963; Utah Geological and Mineral Survey, written commun., 1991). The Navajo aquifer in this area does not extend to this erosional limit. The Navajo Sandstone was determined to be unsaturated near this southern erosional limit by Cordova (1978, pl. 3).

The extent and depth of the aquifer in the northern part of Washington County, where the Navajo Sandstone does not crop out, could not be determined because no wells have been drilled deep enough to penetrate it. On the basis of similarities in structure and geology in areas east of the study area, it was assumed by the author that the Navajo aquifer underlies most of the northern part of the county; however, considering the general northerly inclination of the Navajo Sandstone and the approximate thicknesses of the younger formations of Mesozoic and Tertiary age that are mapped in that part of the county, the Navajo aquifer is probably too deep in most locations to be useful as a water source. If the top of the Navajo Sandstone were projected north using a dip angle of 3 degrees, it would be about 4,600 feet below land surface at the town of Pine Valley, Utah, and about 8,000 feet below land surface at the northern Washington County boundary.

If the assumption about the northern extent is correct, the Navajo aquifer would include an area of about 900 square miles in Washington County west of the Hurricane Fault. The principal recharge areas for the Navajo aquifer, which are the areas where the Navajo Sandstone crops out or is covered only by alluvium or basalt of Quaternary age, would include about 225 square miles.

RELATIVE IMPORTANCE OF RECHARGE AREAS

The relative importance of the recharge areas for the Navajo aquifer was determined by considering climate, geology, topography, hydrology, and hydrography. The relative importance of the different parts of the recharge areas depends on related aspects, including quantity of precipitation, topographic slope, presence and infiltration capacity of surficial deposits, location of intermittent and perennial stream channels, vegetation, soil development, and surface fractures. Recharge mechanisms were outlined in previous investigations (Cordova, 1978; Cordova, Sandberg, and McConkie, 1972) and are summarized in the "HYDROLOGIC SYSTEM" section of this report. Information regarding recharge to the Navajo aquifer, including winter precipitation data, geologic maps, topographic maps, and water-level maps was available from previous investigations.

Precipitation that falls during October through April, referred to as winter precipitation in this report, was used to define areas where potential recharge was greatest or least. Precipitation data were available for 1931-60 from the U.S. Weather Bureau (1963). In southern Utah, winter precipitation is thought to be the major source of recharge to aquifers because temperatures are cool enough so that the evaporation rate is slow, and winter precipitation in the form of snow usually melts slowly, extending the period of runoff and increasing infiltration (Danielson and Hood, 1984, p. 24). Infiltration studies by Danielson and Hood (1984) generally indicate that areas with more than 8 inches of winter precipitation (water equivalent) contributed the most recharge to underlying aquifers.

Geologic maps (Hintze, 1963; Utah Geological and Mineral Survey, written commun., 1991; Cordova, 1978) show the areal extent of Navajo Sandstone outcrops and areas where alluvial material or lava covers the Navajo Sandstone. During months when precipitation falls as rain, alluvium or porous lava can capture runoff and increase infiltration. The more quickly rainfall is absorbed into the ground, the smaller the quantity of water that can evaporate, because of a shorter residence time on the ground when the water may be exposed to wind and sun. This infiltrating water is stored in the covering deposits and eventually infiltrates into the underlying sandstone. Alluvium and lava flows are not as important to recharge potential during the winter, when evaporation rates are slow and rapid runoff generally does not occur. Water from gradual snowmelt tends to infiltrate downward through open fractures in the sandstone faster than through pore space in alluvium or lava; thus, in winter, recharge potential in areas of unexposed sandstone is smaller.

Topographic maps were used to determine areas where the land surface was sufficiently steep to cause rapid runoff and thus prevent substantial infiltration of water. No field studies have been done to determine the degree of slope that would cause this rapid runoff; an angle of 30 degrees was arbitrarily chosen. Areas with a greater than 30-degree slope were delineated by calculating the distance between topographic contours that would represent a 30-degree slope and then outlining areas where the distance between contours was less than the calculated distance. Recharge in these areas was assumed to be negligible.

The water-level maps prepared by Cordova (1978, pl. 3) and Clyde (1987, fig. 6) were used to determine likely areas where recharge is occurring. The gradient defined by the water-level contours indicates that ground water is moving from higher-altitude areas where normal annual and winter precipitation is the greatest. This information implies that recharge to the Navajo aquifer takes place not only in areas where the Navajo Sandstone crops out, but also in areas where it is overlain by younger deposits. As a result, the area north of the outcrop area also was designated a recharge area, although it probably has a smaller recharge potential than the outcrop area.

Stream channels that traverse the Navajo Sandstone are also narrow zones of recharge. Perennial streams are of greatest importance because they are a year-round, uniform source of infiltrating water to the sandstone and to the alluvial and volcanic deposits that cover the Navajo Sandstone. Intermittent streams are less important as recharge sources because they contain water during only part of the year. Streams flowing across younger formations of Mesozoic and Tertiary age north of the outcrop area probably also contribute water to the Navajo aquifer, although the quantity likely would be less than where streams traverse the Navajo Sandstone.

The factors discussed in this section were evaluated jointly to construct a map of recharge potential (fig. 3) to indicate areas that might be considered for future protection. Stream channels that traverse the Navajo Sandstone are probably the most important recharge zones. Recharge areas of slightly lesser importance are probably where normal winter precipitation is greater than 8 inches. Areas where normal winter precipitation is less than 8 inches probably receive a smaller quantity of recharge, but the underlying aquifer is still vulnerable to contamination if the quality of water supplied to the recharge area has been affected by activities on developed land. An example would be irrigation and fertilization of lawns and gardens. Areas where the topographic slope is too steep to allow time for precipitation to infiltrate are probably of least importance as recharge zones.

The scope of this investigation precluded collecting or compiling other information that could be used to better classify recharge areas. A more comprehensive investigation of recharge potential would need to include mapping of density and width of fractures; studying the effects of faults on vertical and horizontal ground-water movement; mapping vegetation type and density; compiling data on soil type, internal drainage characteristics, permeability, and infiltration properties; performing tests to determine the variability in horizontal and vertical hydraulic conductivity of the Navajo and other aquifers; and performing seepage investigations along all intermittent and perennial streams and reservoirs.

CHEMICAL QUALITY OF WATER IN THE NAVAJO AQUIFER

The quality of water in the Navajo aquifer is assumed to be represented by chemical analyses obtained from previous investigations and from periodic sample collection and analysis subsequent to those studies. Samples were collected as early as July 1962 and as recently as March 1992 (table 1, reverse side of sheet) by the U.S. Geological Survey and the Utah Department of Environmental Quality. Results of analyses made by the U.S. Geological Survey were included in previous reports (Cordova and others, 1972; Cordova, 1978). These analyses are presented again in this report. Also included are analyses from the files of the Utah Department of Environmental Quality and analyses of samples collected for this study.

Most of the wells and springs sampled (42 wells and 6 springs) are sources of public supply for St. George and adjacent communities (fig. 4). Because an updated field inventory has not yet been done, the map location of some wells may not be precise. Location was the main criterion for determining if a well or spring was producing from the Navajo aquifer; thus, a few of the analyses shown in table 1 may be from wells producing from the Kayenta Formation.

In 1989, the State of Utah defined a classification system for ground water and aquifers on the basis of chemical quality of the water (Utah Department of Health, 1989). The purpose of the classification system was to enable regulators to establish different levels of protection for different categories of water. The categories are listed in table 2, part A, and the established water-quality standards are listed in part B. These standards are being reviewed (1993) and may change at a later date.

It is not the purpose of this report to classify the Navajo aquifer with respect to water quality. Because sufficient sampling locations are not available, the Navajo aquifer would be difficult to classify, as a whole. Water from parts of the aquifer where wells and springs were sampled generally would be classified as either Class I or II; Pristine (IA), Irreplaceable (IB), Ecologically Important (IC), or Drinking-Water Quality (II).

Water in the Navajo aquifer generally contains less than 1,500 mg/L dissolved solids (table 1), and about 70 percent of the samples analyzed contained less than 500 mg/L dissolved solids. Concentrations of the inorganic or organic constituents and metals were less than the State's 1989 ground-water-quality standards in all samples for which these parameters were tested. Radium-226 plus gross alpha particle activity exceeded the State's limit of 15 pCi/L in one sample from well (C-42-15)6dcd-1, collected on April 2, 1985, but not in samples from the same well collected prior to or after that date. Gross beta activity was 16 pCi/L, but strontium-90 was less than 1 pCi/L. Some wells and springs have been sampled periodically for years. Comparison of the analyses of the water indicates that no appreciable change has occurred with time in the concentration of any constituent.

Table 2. *Utah ground-water classification system and water-quality standards*

Part A. Classification

Class number	Class name	Class requirements
IA	Pristine	Dissolved-solids concentration less than 500 milligrams per liter; no constituents isted in part B are exceeded
IB	Irreplaceable	Same as class IA; no other reliable supply reasonably available
IC	Ecologically Important	Same as Class IA; constitutes a source necessary for the existence of a wildlife habitat
II	Drinking-Water Quality	Dissolved-solids concentration less than 3,000 milligrams per liter and greater than 500 milligrams per liter; no constituents listed in part B are exceeded
III	Limited Use	Dissolved-solids concentration less than 10,000 milligrams per liter and greater than 3,000 milligrams per liter and/or one or more constituents listed in part B are exceeded
IV	Saline	Dissolved-solids concentration greater than 10,000 milligrams per liter
	Unclassified	Unknown

Part B. Water-quality standards

Constituent or characteristic	Maximum allowable concentration, in micrograms per liter, unless noted otherwise
Metals	
Arsenic	50
Barium	1,000
Cadmium	10
Chromium	50
Copper	1,000
Lead	50
Mercury	2
Selenium	10
Silver	50
Zinc	5,000
Inorganic chemicals	
Fluoride	2.4 milligrams per liter
Nitrate (as nitrogen)	10 milligrams per liter
Organic chemicals (Pesticides)	
2,4-D	100
2,4,5-TP (Silvex)	10
Endrin	0.2
Lindane	4
Methoxychlor	100
Toxaphene	5
Volatile organic chemicals	
Benzene	5
Carbon tetrachloride	5
Trichloroethylene	5
Vinyl chloride	2
1,1-Dichloroethylene	7
1,2-Dichloroethane	5
1,1,1-Trichloroethane	200
1,4-Dichlorobenzene	75
Radionuclides	
Gross-alpha-particle activity (including radium-226)	15 picocuries per liter
Combined radium-226 and radium-228	5 picocuries per liter

SUMMARY

The Navajo aquifer underlies about 900 square miles in western Washington County, mostly in the north and central part of the study area. The Navajo aquifer also exists in the eastern part of the county but is hydrologically isolated from the western part by the large throw of the Hurricane Fault. Most of the recharge to the Navajo aquifer occurs at the outcrop of the Navajo Sandstone. The Navajo Sandstone crops out north of the incorporated areas of St. George, Santa Clara, Washington, and other towns, and also west of the Hurricane Fault south and north of the town of Hurricane, Utah.

Recharge rates in different parts of the recharge area depend on climate, geology, topography, hydrology, and hydrography. Specific aspects include quantity of precipitation, topographic slope, presence and infiltration capacity of surficial deposits, location of intermittent and perennial stream channels, vegetation, soil development, and surface fractures. Only precipitation, presence of surficial deposits, slope, and location of streams were considered. Areas of greatest recharge are probably along perennial streams crossing the Navajo Sandstone. Areas of least recharge are probably where the topographic slope is too steep to allow precipitation to infiltrate into the aquifer.

Water in the Navajo aquifer at locations sampled is of Drinking-Water Quality or better, according to the Utah Department of Health (1989) classification system. Dissolved-solids concentration generally was less than 1,500 mg/L and was less than 500 mg/L in about 70 percent of the samples collected from wells and springs in the Navajo aquifer. Concentrations of metals and organic compounds were less than the State of Utah's 1989 standards.

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Explanation

- Area where Navajo aquifer is buried
- **Area where Navajo Sandstone crops out or is covered with Quaternary alluvium or volcanics** – Excludes area where Navajo Sandstone is unsaturated
- Spring discharge area
- Corporate boundary
- **Well** – Number is map number shown in table 1
- **Spring** – Number is map number shown in table 1

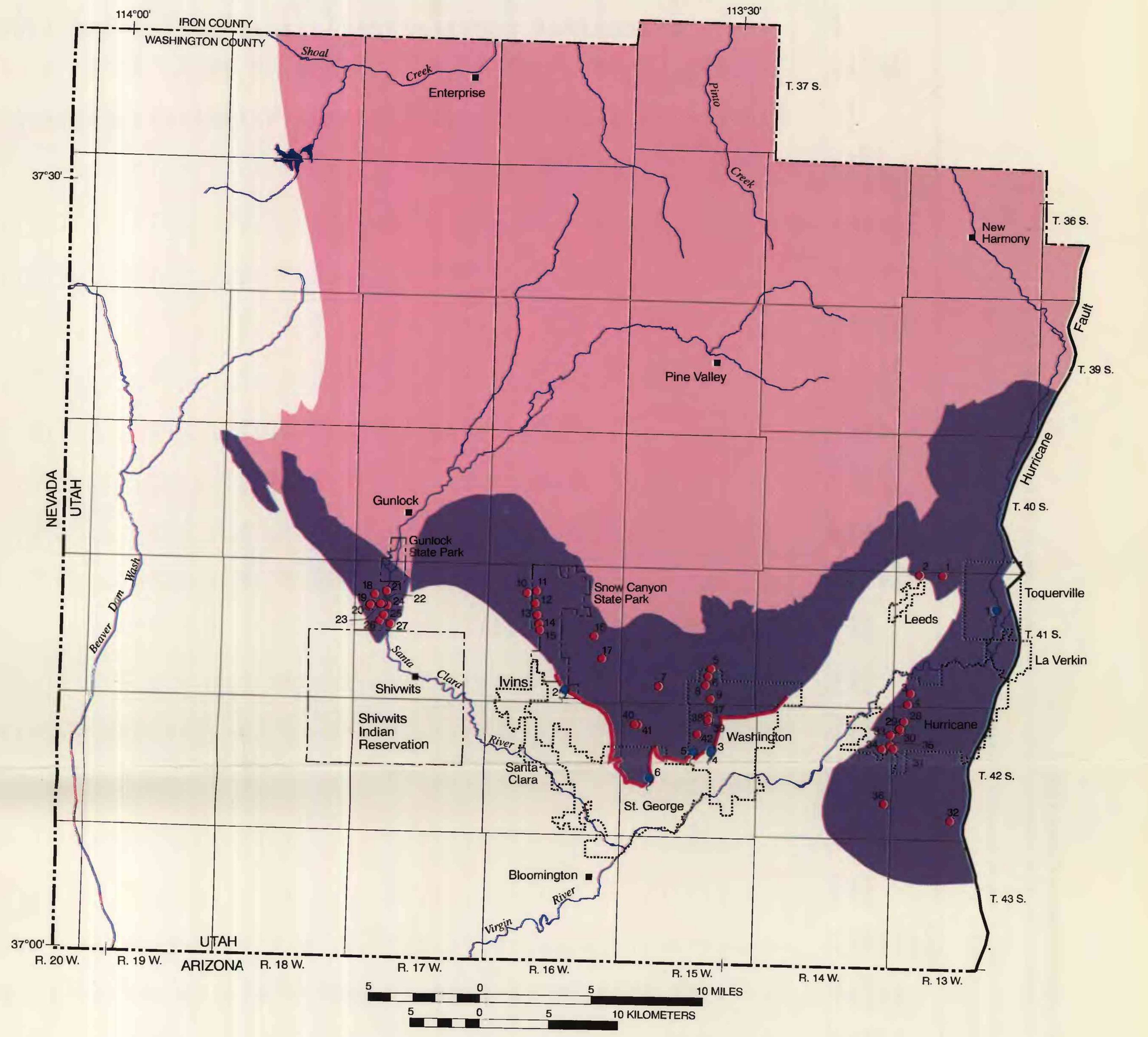

Figure 4. Location of sampled wells and springs.

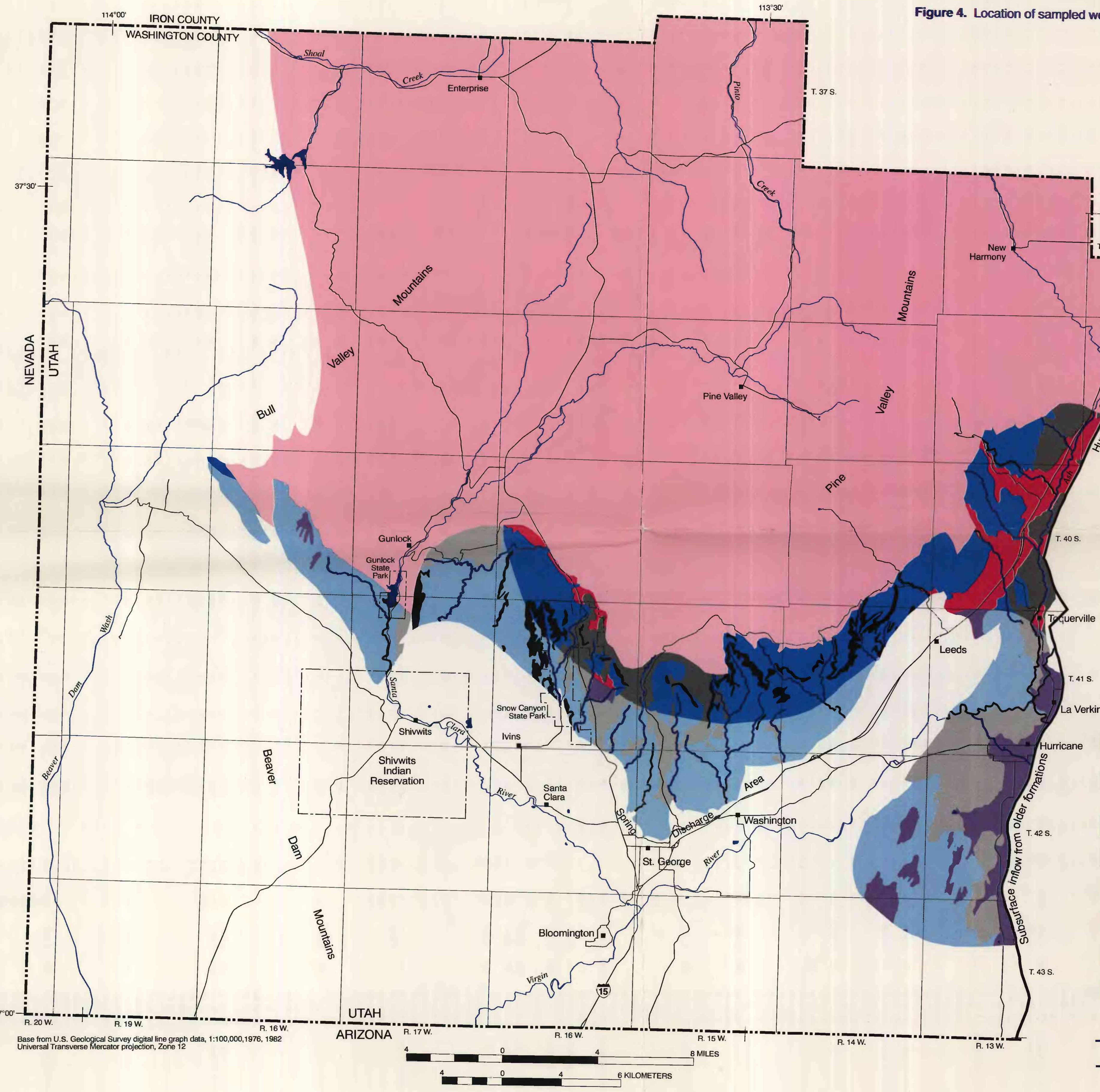

Figure 3. Recharge areas for the Navajo aquifer.

Explanation

Relative recharge potential	Winter precipitation	Recharge character	Surficial geologic formation
Negligible	Less than 10 inches	Slope too steep to allow time for infiltration	Navajo Sandstone and Quaternary basalt or alluvium overlying Navajo Sandstone
Negligible to low	Mostly greater than 8 inches – as large as 25 inches	Infiltration greatest near southern extent where depth to top of Navajo Sandstone is least; negligible where Navajo Sandstone deeply buried	Younger Mesozoic, Cretaceous, and Tertiary sedimentary and igneous rocks
Negligible to low	Less than 6 inches	Infiltration unlikely except during infrequent thunderstorms in areas with open fractures	Navajo Sandstone
Negligible to low	Less than 8 inches	Infiltration minimal except during infrequent thunderstorms in areas where basalt is porous	Quaternary basalt
Low	Less than 8 inches	Infiltration more likely; runoff less likely on unconsolidated granular material	Quaternary alluvium or eolian deposits
Low to moderate	Greater than 8 inches	Infiltration of snowmelt rapid if deposits do not contain substantial silt or clay, such as southwest of Hurricane, Utah	Quaternary alluvium or eolian deposits
Low to moderate	Greater than 6 inches	Infiltration of snowmelt rapid where basalt is broken and fractured; minimal if unbroken	Quaternary basalt
Moderate to high	Greater than 8 inches	Infiltration of snowmelt rapid in areas of open fractures; slower through pores of sandstone	Navajo Sandstone

Relative stream infiltration

- Moderate - Reach of stream where recharge occurs intermittently when stream channel contains water
- High - Reach of stream where recharge occurs at all times

MAPS SHOWING RECHARGE AREAS AND QUALITY OF GROUND WATER FOR THE NAVAJO AQUIFER, WESTERN WASHINGTON COUNTY, UTAH

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1993

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