THE NAVAJO AQUIFER SYSTEM OF SOUTHWESTERN UTAH

Geological Society of America 2002 Rocky Mountain Section Annual Meeting
Cedar City, Utah
May 6, 2002

Outcrop of the Navajo Sandstone near Washington, Utah, in the foreground, with the Pine Valley Mountains in the background.

FIELD TRIP LEADERS

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INTRODUCTION

This one-day field trip begins and ends in Cedar City, Utah. Field trip stops will focus on recharge to, movement within, and discharge from the Navajo aquifer system within the central Virgin River basin area (figure 1). The Navajo aquifer system, defined as the combination of the water-bearing parts of the Navajo Sandstone and the Kayenta Formation, provides the majority of municipal water to southwestern Utah. Rapid population growth in this warm and arid region is putting pressure on ground-water managers to further develop this resource in a sustainable manner. In order to do this, spatial and temporal variations in recharge to the aquifer, ground-water residence times, and points of discharge have been quantified during recent studies by the U.S. Geological Survey, the U.S. Bureau of Reclamation, and the University of Utah.

Deposition of the Navajo Sandstone occurred under eolian conditions. It is a well sorted, fine-grained sandstone, with a total thickness between 2,000 and 2,400 feet in the central Virgin River basin area (figure 2). The Kayenta Formation consists of laminar beds of sandstone, siltstone, and silty mudstone, with a total thickness varying between 400 and 900 feet. Located just west of the Colorado Plateau boundary (defined as the Hurricane fault), the formations generally dip toward the north, yet are offset by a series of normal faults, including the Washington Hollow fault, the Snow Canyon fault, and the Gunlock fault. Another prominent structural feature is the Virgin River anticline, which has resulted in uplift and erosion of the Navajo Sandstone and Kayenta Formation.

Most recharge to the Navajo aquifer occurs as diffuse infiltration of precipitation where the Navajo Sandstone crops out or is covered by a thin veneer of surficial soils. Precipitation along the outcrop ranges from 8 to 18 inches per year (figure 1). Detailed studies at Sand Hollow basin show that the amount of diffuse recharge from infiltrating precipitation varies widely and is primarily dependent on runoff from steeply dipping slickrock and the coarseness of surficial soil cover. Other sources of recharge include seepage from perennial and ephemeral streams, infiltration of unconsumed irrigation water, and seepage from underlying formations (figure 3). Recharge to the aquifer in Washington County (west of the Hurricane fault) is estimated at 14 to 59 cubic feet per second (table 1; Heilweil and others, 2000).

Table 1. Estimated ground-water budget for the Navajo aquifer, central Virgin River basin, Utah

	Flow component	Volume (cubic feet per second)
Recharge	Infiltration of precipitation	11 to 33
	Seepage from perennial streams and reservoirs	3 to 13
	Seepage from ephemeral streams	0.3 to 4
	Seepage from underlying formations	0 to 4
	Infiltration of unconsumed irrigation water	0 to 5
	Total Recharge (rounded)	**14 to 59**
Discharge	Well discharge	15 to 23
	Spring discharge	7 to 9
	Seepage to perennial streams (Virgin, Santa Clara Rivers)	7 to 9
	Seepage to underlying formations	0 to 8
	Total Discharge (rounded)	**29 to 49**

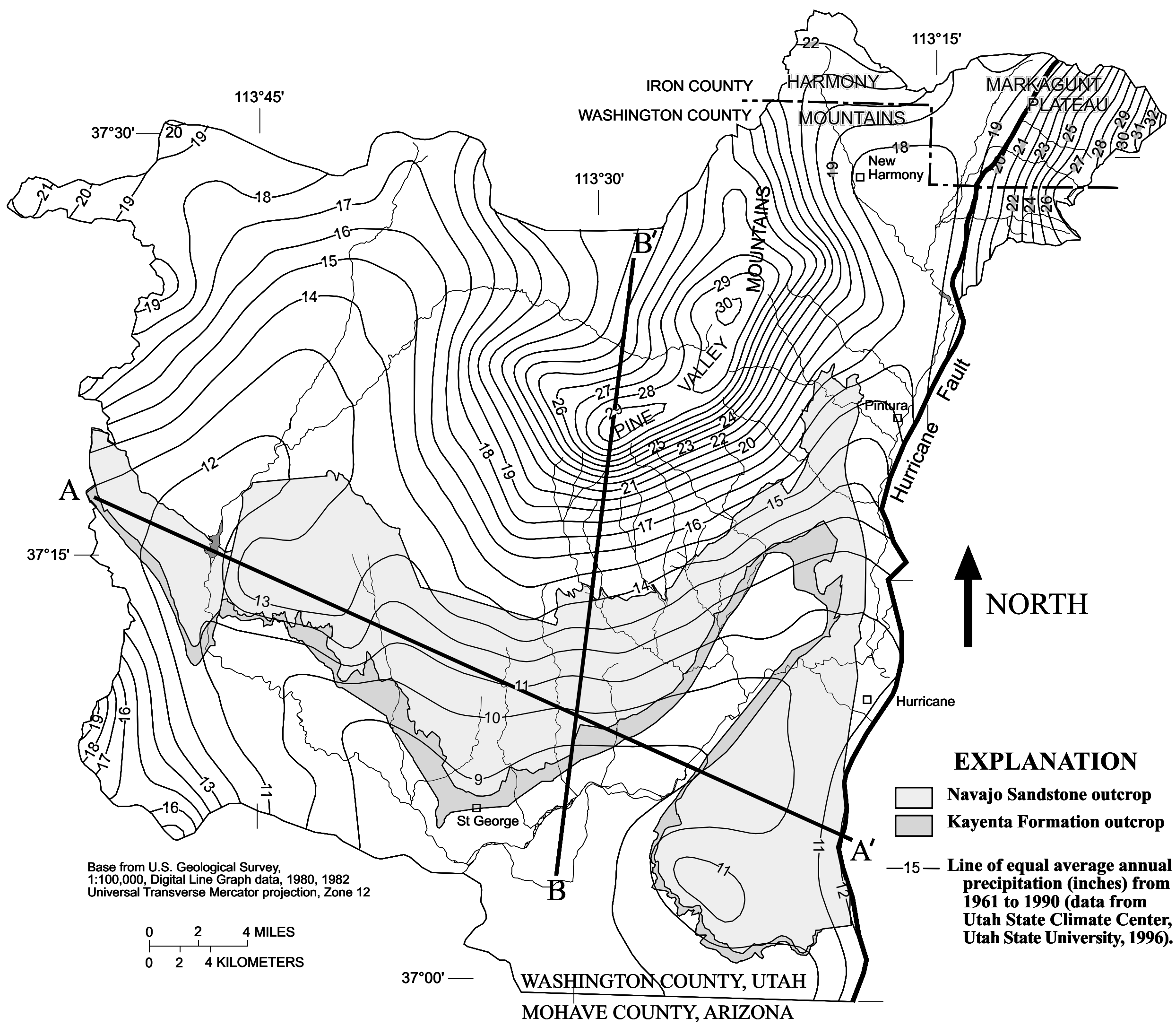

Figure 1. Average annual precipitation contours (1961-1990), location of the Navajo Sandstone and Kayenta Formation outcrops, and location of cross sections (see figure 1) for the central Virgin River basin area, Utah.

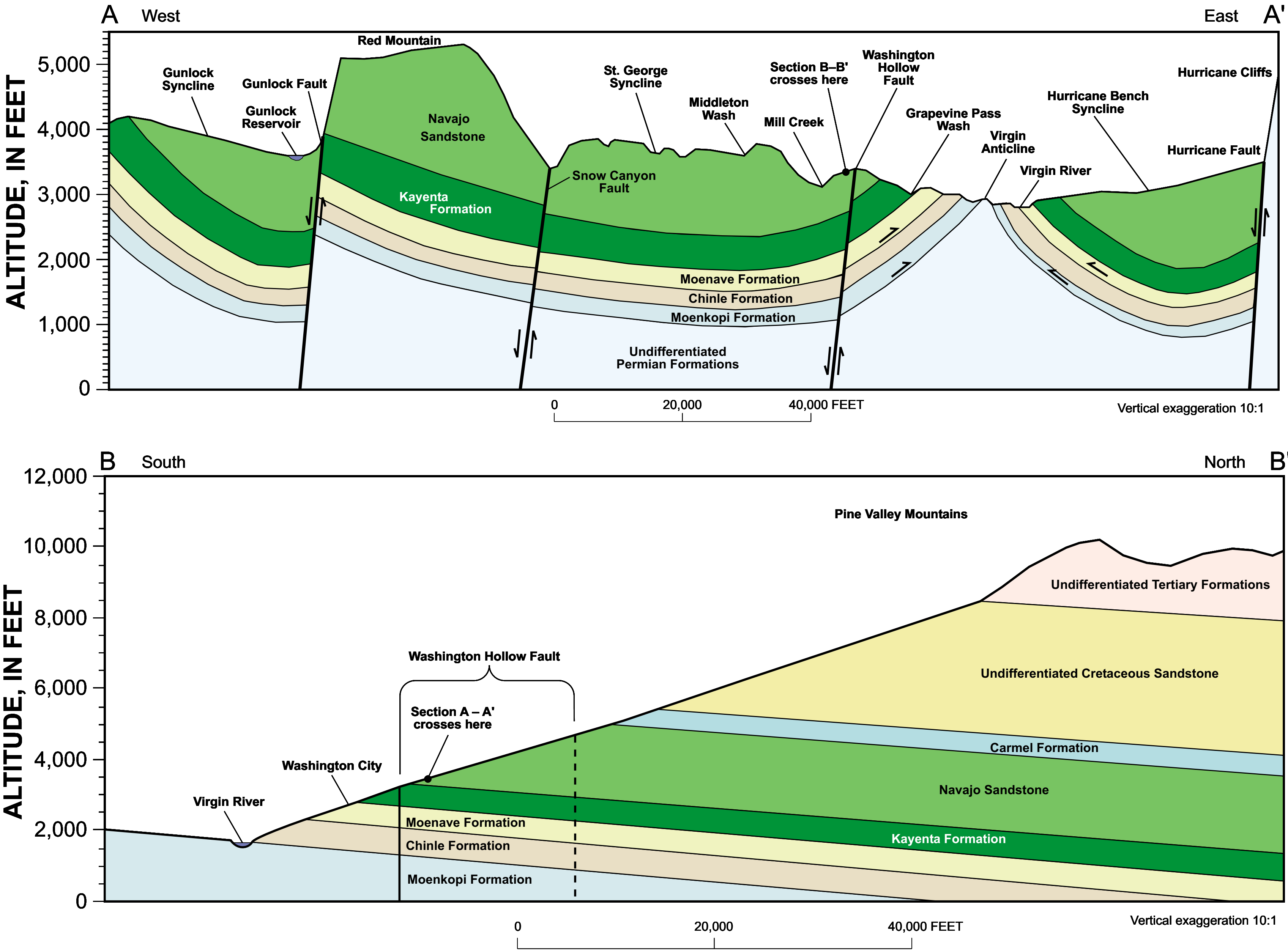

Figure 2. Generalized geologic cross sections of the Navajo Sandstone, Kayenta Formation, and surrounding formations within the central Virgin River basin study area, Utah. Cross-section locations shown in Figure 2.

Ground water within the Navajo aquifer generally moves from the northern higher-elevation recharge areas along the perimeter of the Pine Valley Mountains toward discharge points farther south. Based on ground-water age dating and modeling, residence times for travel through the aquifer range from tens to thousands of years (Heilweil and others, 1997). These flow rates depend on a combination of hydraulic gradient (steepness of the potentiometric surface) and hydraulic conductivity. While the primary permeability through the intergranular porosity of the sandstone is significant, secondary fracturing greatly enhances this permeability by more than an order of magnitude, as well as causing an anisotropic hydraulic conductivity tensor.

Well withdrawals are the main source of discharge from the aquifer. Other sources include spring discharge, seepage to the Virgin River, and seepage to underlying formations (figure 3). Total discharge from the aquifer in Washington County (west of the Hurricane fault) is estimated at 29 to 49 cubic feet per second (table 1; Heilweil and others, 2000). The recent increase in well withdrawals has intercepted ground-water flow from other natural discharge sources, such as springs and streams. An example of this is the Santa Clara River below Gunlock Reservoir, where increased ground-water pumping during the last three decades has changed this from a gaining to a losing stream reach. The increase in well withdrawals also has resulted in regional water-level declines within the aquifer on the order of tens of feet.

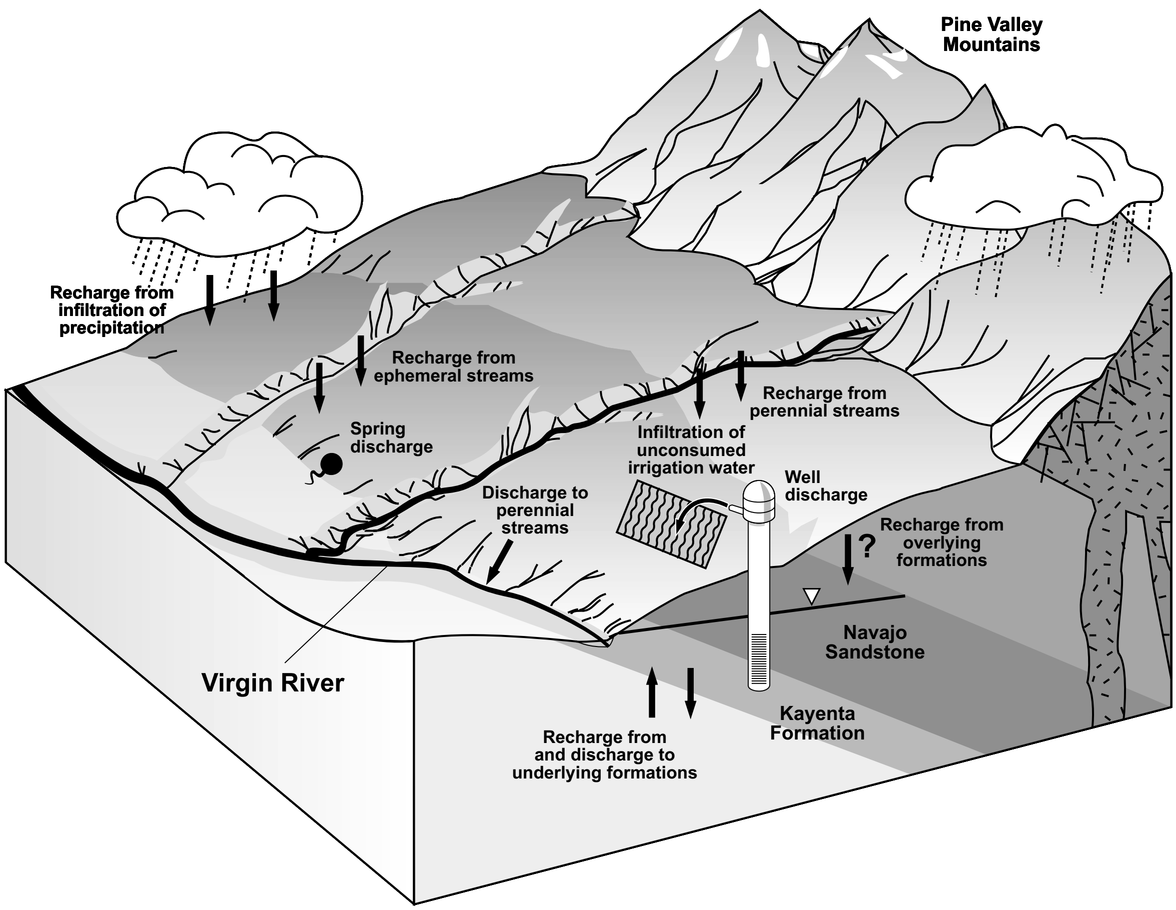

Figure 3. Generalized diagram showing sources of recharge to and discharge from the Navajo aquifer within the central Virgin River basin area, Utah.

Because of limited water resources and further projected growth, the Washington County Water Conservancy District (WCWCD) has been actively planning artificial recharge projects to enhance natural recharge to the Navajo aquifer. The nearly completed Sand Hollow Reservoir near Hurricane, Utah, will serve primarily as a ground-water recharge and recovery project to store Virgin River water during higher snowmelt runoff periods. Similarly, preliminary studies along Sand Cove Wash are underway to evaluate the potential for using excess snowmelt runoff in the Santa Clara River for enhancing recharge to the Navajo aquifer.

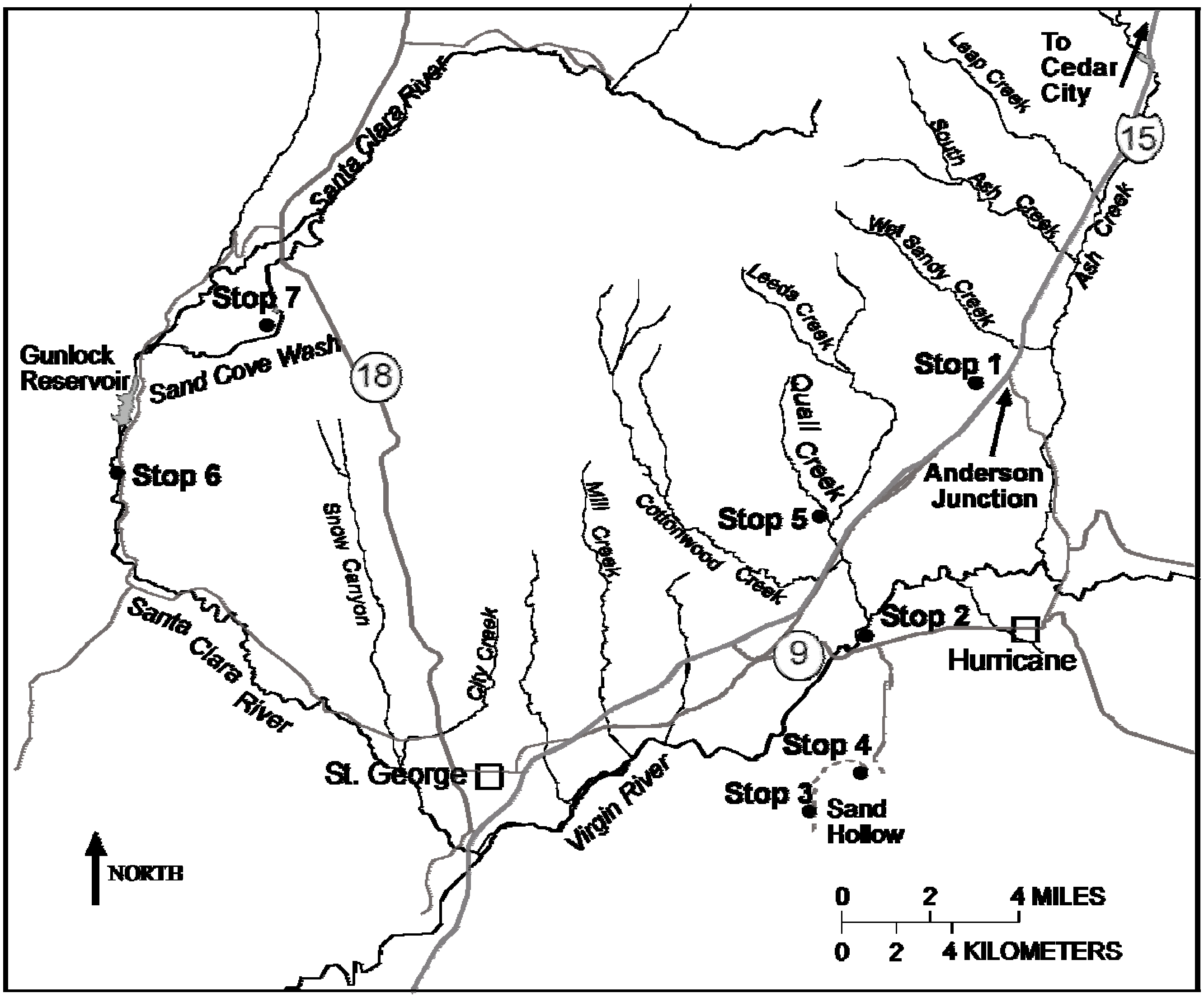

Figure 4. Map showing location of field trip stops.

ROAD LOG

Increment mileage	Cumulative mileage	Description
0.0	0.0	Begin trip at Southern Utah University parking lot near corner of 200 South and 1150 West. Left on 1150 West heading north.
0.2	0.2	Left on Center Street across freeway.
0.3	0.5	Right at stop sign on College Way (1650 West).
0.3	0.8	Right at stop light on 200 North.
0.3	1.1	Right onto southbound I-15 entrance ramp at exit 59.
31.0	32.1	Toquerville Exit, Route 17. South on frontage road.

1.0 33.1 **STOP NO. 1A.** INTRODUCTION AND OVERVIEW: Discussion leader: Kimball Goddard, U.S. Geological Survey; **STOP NO. 1B.** ANDERSON JUNCTION WELL FIELD: Discussion leaders: Hugh Hurlow, Utah Geological Survey; Vic Heilweil, U.S. Geological Survey.

The Navajo Sandstone and Kayenta Formation are extensively fractured, resulting in enhanced secondary permeability of the aquifer. Large variations in hydraulic conductivity within the Navajo aquifer observed during four aquifer tests, conducted by the U.S. Geological Survey (figure 5), are attributed to this fracturing. Hydraulic-conductivity values determined from these tests ranged from 0.2 to 32 feet per day (table 2).

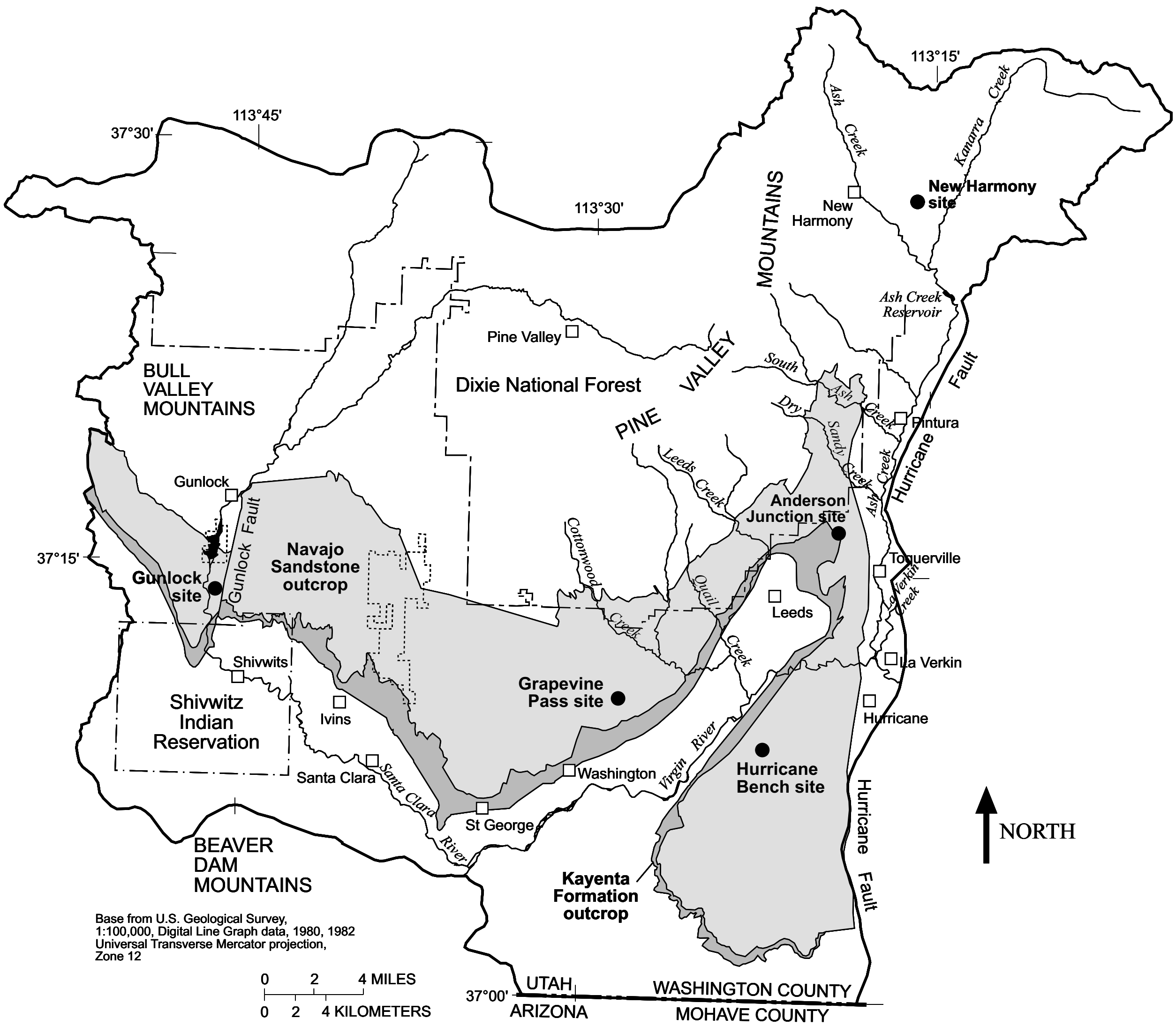

Figure 5. Location of the four Navajo aquifer test sites within the central Virgin River basin study area, Utah.

Table 2. Aquifer-test results from the Navajo aquifer, central Virgin River basin study area, Utah

Location	Number of observation wells	Pumping/ recovery period (days)	Horizontal hydraulic conductivity (feet/day)	Saturated thickness (feet)	Transmissivity ($feet^2$/day)	Storage coefficient
Anderson Junction	2	4	1.3 to 32	600	1,800 to 19,000	.0007 to .0025
Hurricane Bench	5	5	2.2	500	1,075	.002
Grapevine Pass	20	1	0.2	500	100	----
Gunlock well field	6	6	0.3 to 1.0	1,100	360 to 1,100	.001

The Anderson Junction aquifer test produced the largest hydraulic-conductivity values, corresponding to higher-than-average fracture density measurements taken along sandstone outcrops (Hurlow, 1998, table G.3). Based on these outcrop fracture density measurements, the WCWCD drilled two observation wells perpendicular to each other about 380 feet south and east of the production well (figure 6).

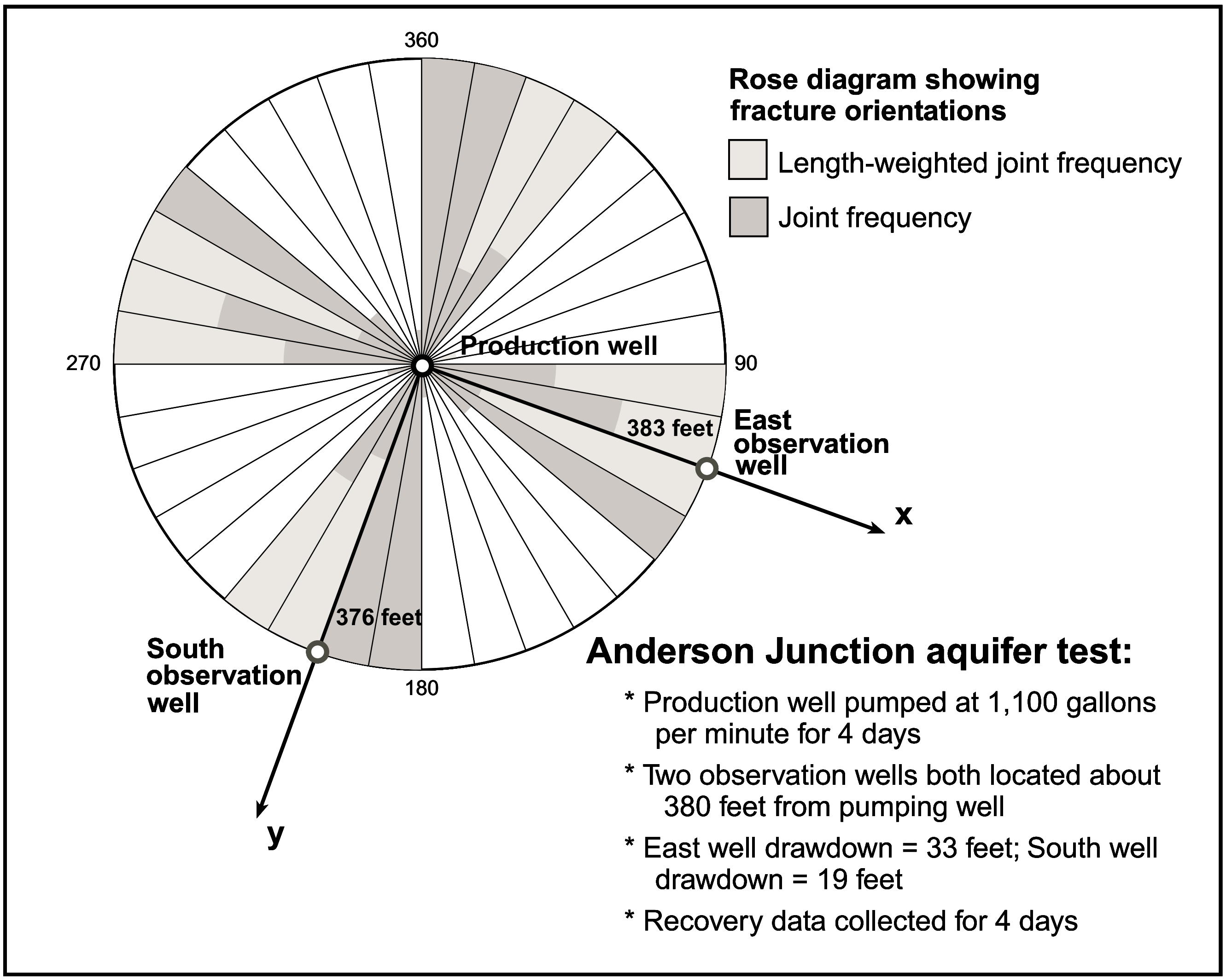

Figure 6. Location of production and observation wells for Anderson Junction aquifer test superimposed on a Rose diagram of outcrop fracture orientations, central Virgin River basin area, Utah.

Large differences in drawdown and recovery at the two wells indicated anisotropic conditions within the sandstone. Data interpretation using a modified version of the Papadopulos method (1965), indicates that hydraulic conductivity varies over 1.5 orders of magnitude because of secondary fracturing (Heilweil and Hseih, 1998). Calculated hydraulic-conductivity values ranged from 1.3 feet per day in the north-south direction to about 32 feet per day in the east-west direction (table 2).

1.0	34.1	Right on Route 17 toward Toquerville.
13.8	47.9	Right before Brentwood Bowling Alley on Hydro-plant road.
1.5	49.4	Left on gravel road.
0.5	49.9	**STOP NO. 2**. VIRGIN RIVER OVERLOOK: Discussion Leader: Vic Heilweil, U.S. Geological Survey.

The Virgin River acts as the primary natural drain for the Navajo Sandstone aquifer west of the Hurricane fault. A seepage study conducted in November 1994 (Herbert, 1995) determined that about 7.2 cubic feet per second directly discharged from the Navajo Sandstone aquifer into the Virgin River, and up to an additional 3.5 cubic feet per second discharged from the sandstone into alluvial deposits along the river (Heilweil and others, 2000). The sources of this discharging ground water include both flow from the north (Anderson Junction area) and flow from the south (Hurricane Bench).

0.5	50.4	Right on Hydro-plant road.
1.5	51.9	Left on Route 17.
0.1	52.0	Left on Floratech Road.
2.5	54.5	Right on gravel road at “Sand Dunes / Sand Hollow View Area” sign.
1.4	55.9	Left at “Y” intersection toward “View Area” (red sign).
0.5	56.4	**STOP NO. 3**. SAND HOLLOW RESERVOIR: Park at the south end of the viewing area. Discussion leaders: Ron Thompson, Washington County Water Conservancy District; Dennis Watt, U.S. Bureau of Reclamation; Vic Heilweil, U.S. Geological Survey.

This is the site of the WCWCD Sand Hollow ground-water recharge and recovery project. The North and West dams will impound surface water that should recharge the underlying Navajo aquifer. Average depth to ground water beneath the basin is about 100 feet. Surface water will be pumped to this off stream reservoir from the Virgin River during periods of high flow, such as spring snowmelt runoff. Infiltration from the conservation pool within the surface-water reservoir will likely be relatively low because of siltation and biofilm development along the reservoir bottom. Infiltration of water stored above the highest conservation pool elevation during higher inflows can be partially managed by scraping the upper margin of the reservoir bottom prior to these seasonal inflows. Scraping would enhance infiltration by breaking up the silt and biofilm deposited during the previous filling cycle. Infiltration rates also can be managed by pumping production wells around the reservoir perimeter to alter the slope of the underlying water table.

Construction of Sand Hollow Reservoir provided unique data-collection opportunities for investigating natural recharge to this basin. The WCWCD drilled more than a dozen observation wells in this small 40 square kilometer basin, which were also used for investigating movement through the unsaturated zone using environmental tracers. The WCWCD also excavated almost 10,000 feet of trenches to depths between 10 and 20 feet, allowing for detailed investigation of unsaturated-zone solutes on a basin-wide scale. The U.S. Geological Survey collected over 800 samples from the trench walls and prepared leachates (by mixing with deionized water). The specific conductance of these leachates revealed large variability in naturally accumulating, unsaturated-zone solutes (figure 7). Areas without large accumulations of solutes indicate regions where active recharge from infiltrating precipitation occurs. Conversely, areas with substantial solute accumulation indicate places where plant roots effectively capture most infiltration passing through the surficial soils. This evapotranspiration of pure water causes the concentration of solutes (from precipitation and atmospheric deposition) in the unsaturated zone.

The U.S. Geological Survey and the U.S. Bureau of Reclamation conducted a soil moisture survey adjacent to the trenches after a month of above-normal precipitation. The results indicate that areas where infiltrating precipitation is able to quickly reach the bedrock contact had correspondingly little solute accumulation in the underlying bedrock trench. Laboratory particle-size analysis of these surficial soils showed a similar correlation between grain size and accumulation of solutes in the underlying bedrock. Areas where surficial soils were coarser generally correspond to areas in the underlying trench with little or no accumulation of solutes in the unsaturated zone of the Navajo Sandstone. This indicates that infiltrating moisture can move more quickly past the root zone and into the underlying Navajo Sandstone in areas with coarser-grained soils, thus escaping interception by plant roots. In these active recharge areas, evapotranspiration and solute concentration are minimal. Conversely, areas with finer soils are able to store more water because of higher porosity and capillarity. In these regions, plant roots are able to use most of this infiltration, resulting in higher evapotranspiration rates and substantial solute accumulation in the underlying Navajo Sandstone (Heilweil and Solomon, 2001).

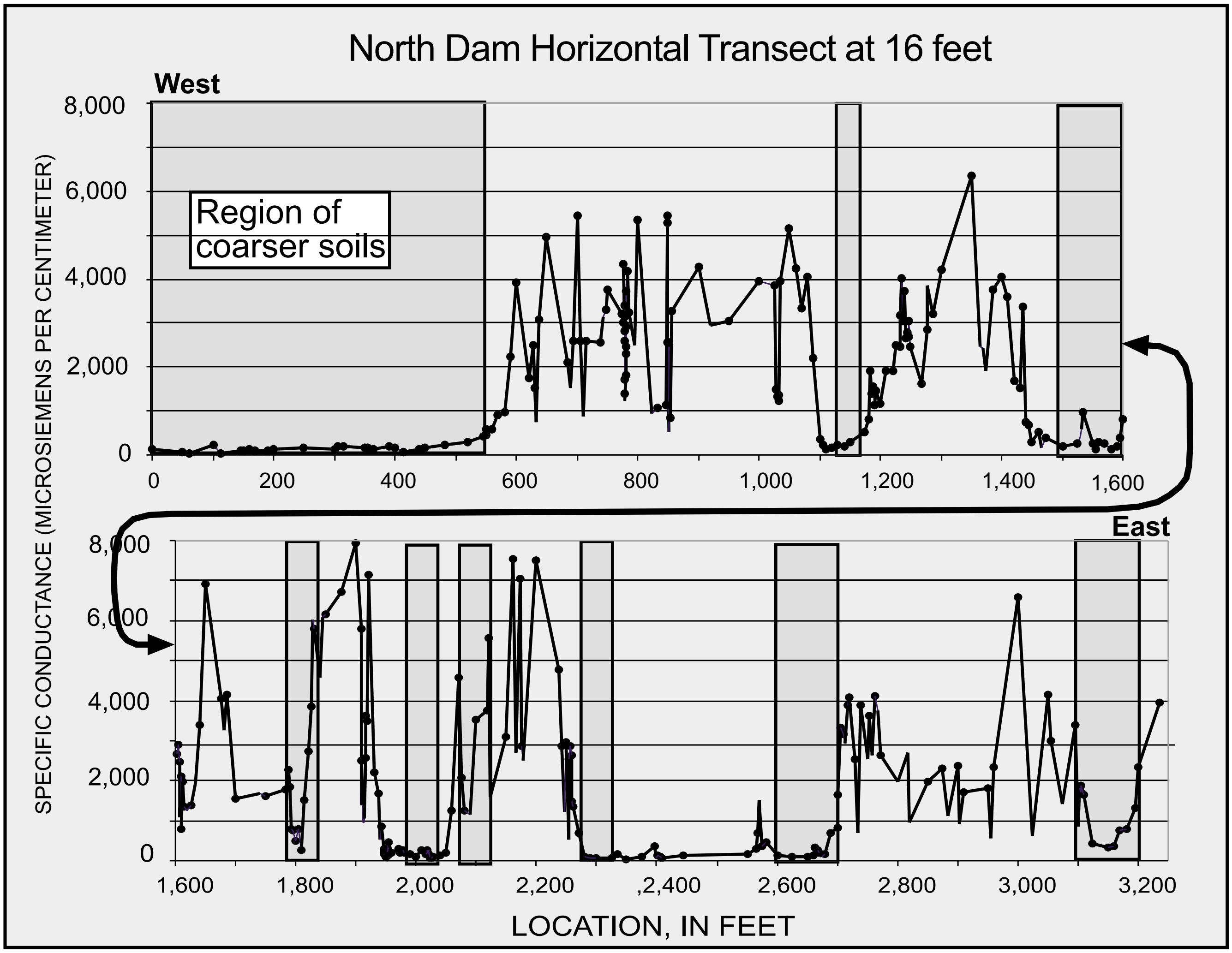

Figure 7. Solute concentrations of leachates along the bottom of the North Dam trench and relationship to coarseness of surficial soils, Sand Hollow basin, Utah.

The U.S. Geological Survey and the University of Utah analyzed chloride, tritium, and stable isotope (hydrogen and oxygen) concentrations of precipitation, unsaturated-zone pore water, and ground water to further evaluate recharge to Sand Hollow basin. The chloride mass balance method was used to estimate average recharge for the entire basin. This method compares average chloride concentration in precipitation to that of ground water. For Sand Hollow basin, that ratio is about 5 percent of precipitation, indicating about 0.4 inch of recharge annually. However, the variation in ground-water chloride concentrations from wells (from 3 to

60 mg/l) indicates considerable spatial variability throughout the basin. Chloride concentrations in unsaturated-zone pore waters are also elevated in many parts of the basin (up to 30,000 mg/l), indicating that solutes from precipitation have been accumulating for thousands of years. These accumulations are caused by plant evapotranspiration in areas with finer-grained soils, which can store more moisture. The large chloride accumulations show that plants can effectively utilize most of the infiltrating precipitation in these areas, resulting in little recharge. Therefore, large unsaturated-zone pore-water chloride concentrations in the underlying sandstone generally correlate with regions of higher ground-water chloride.

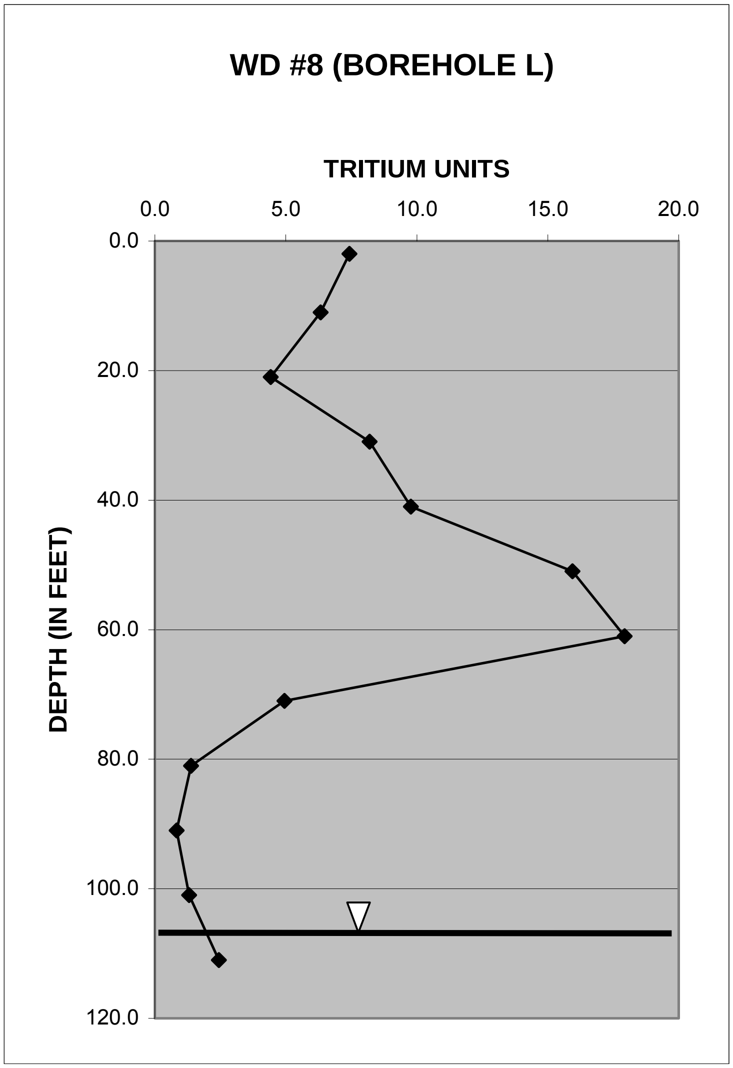

Figure 8. Profile of unsaturated-zone pore-water tritium from WD #8 well (borehole L), Sand Hollow basin, Utah.

Similar to the chloride mass balance method, the mass of anthropogenic tritium in the unsaturated zone can be compared to the amount of tritium in precipitation to estimate recharge rates. Figure 8 shows one unsaturated-zone tritium profile from a high recharge area at the base of a large exposure of sandstone outcrop. Note that the peak concentration (greater than 12 tritium units) at a depth of about 60 feet represents precipitation that fell during the early 1960's peak in above ground nuclear testing. On the basis of unsaturated-zone pore-water tritium profiles, recharge rates at Sand Hollow vary from around 0.5 to over 7 percent of precipitation. There is a strong correlation between areas with high recharge rates, based on unsaturated-zone tritium, and low unsaturated-zone solute accumulations. On the basis of trench and borehole core samples, the unshaded areas of figure 9 are regions within Sand Hollow basin with little solute accumulation in the unsaturated zone. Recharge rates in these areas, based on unsaturated-zone tritium, generally are greater than

1 percent of precipitation. Conversely, the shaded areas represent regions with substantial accumulation of unsaturated-zone solutes. Recharge rates in these areas generally are less than 1 percent of precipitation.

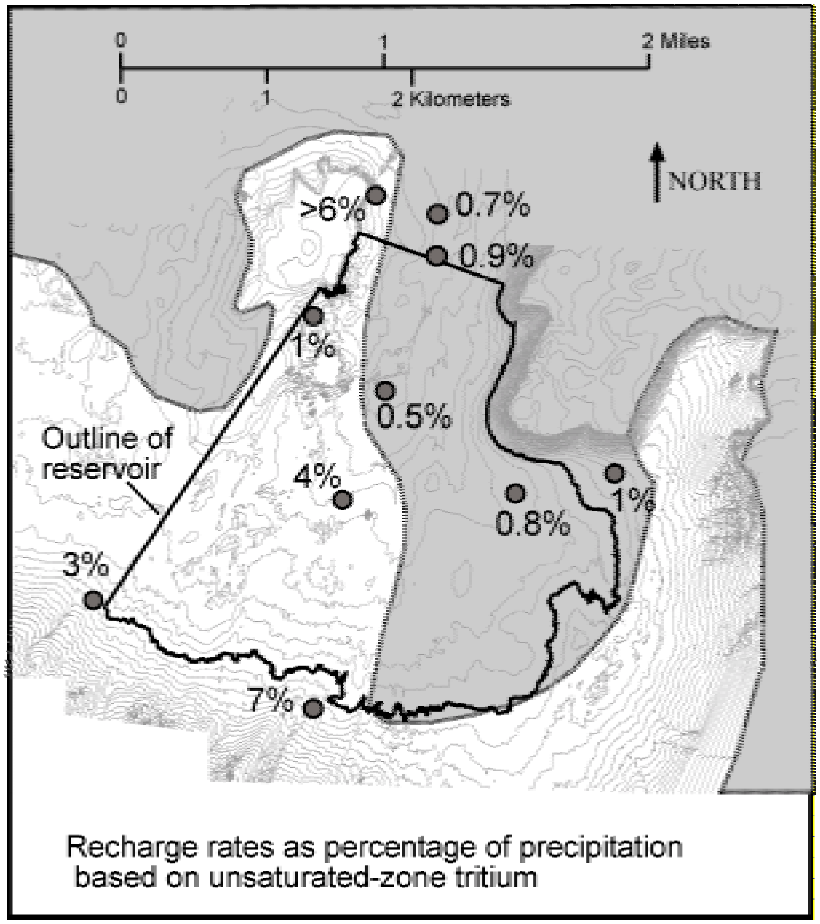

Figure 9. Relation between area of high unsaturated-zone solute accumulation (shown by gray shading) and higher recharge rates (based on unsaturated-zone tritium) at Sand Hollow basin, Utah.

2.3	58.7	Right on North Dam access road.
0.9	59.6	Right on dirt road before dam (then pass construction trailers on right).
0.2	59.8	**STOP NO. 4.** INFILTRATION POND EXPERIMENT SITE: Discussion leaders: D. Kip Solomon, University of Utah; Dennis Watt, U.S. Bureau of Reclamation; Vic Heilweil, U.S. Geological Survey.

This is the site of a 10-month infiltration experiment conducted by the U.S. Geological Survey, the U.S. Bureau of Reclamation, and the University of Utah to better estimate expected seepage rates beneath Sand Hollow Reservoir. After the first few days, net infiltration rates ranged from about 0.13 to 0.23 feet per day of water (fig. 10). These rates account for evaporation, which varied from 0.002 feet per day in the winter to 0.042 feet per day in the summer. It is likely that long-term seepage rates beneath Sand Hollow Reservoir will be much lower due to: (1) a decreasing hydraulic gradient once the ground-water mound connects with the saturated wetting front; and (2) siltation and biofilm development on the bottom of the reservoir. A feasibility study by EWP Engineering (1997) describes a Hantush calculation of 19 cubic feet per second of seepage beneath Sand Hollow Reservoir without considering reductions due to clogging. They estimated that siltation and biofilm development may reduce actual long-term seepage rates to about 10 cubic feet per second, or a rate of 0.04 feet per day, which is one quarter of the initial rates based on results from the infiltration pond experiment.

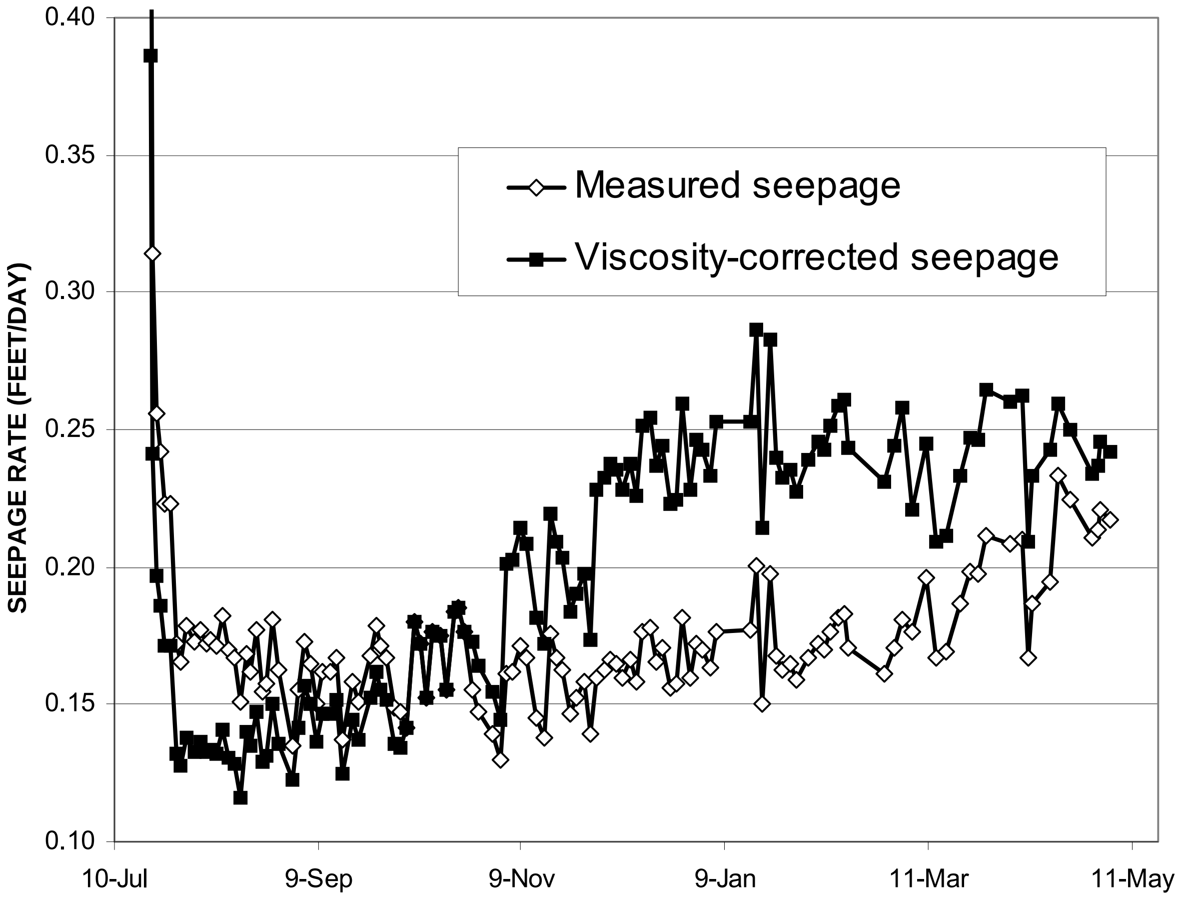

Figure 10. Seepage rates during the infiltration pond experiment at Sand Hollow basin, Utah.

The infiltration pond seepage rates were lower than expected based on laboratory permeability testing of the Navajo Sandstone and variably saturated flow modeling. It is thought that these lower rates were due to a combination of (1) trapped gas and/or biofilm development beneath the pond, and (2) a low-permeability layer of caliche along the top of the Navajo Sandstone contact. A dissolved-helium tracer was added to the pond to evaluate the percentage of trapped gas in the subsurface. Because of its low solubility, the helium readily partitioned into any trapped gas encountered. Its retardation, with respect to a conservative bromide tracer (figure 11), indicates that up to 8 percent of the total porosity was filled with trapped gas. Theoretically, this gas would exist mostly in the larger pore-throats and could result in a factor of 10 decrease in hydraulic conductivity. Figure 10 also shows seepage rates corrected for the variation in viscosity caused by changes water temperature. The increased viscosity-corrected seepage rates during the fall are likely caused by the dissolution of trapped gas.

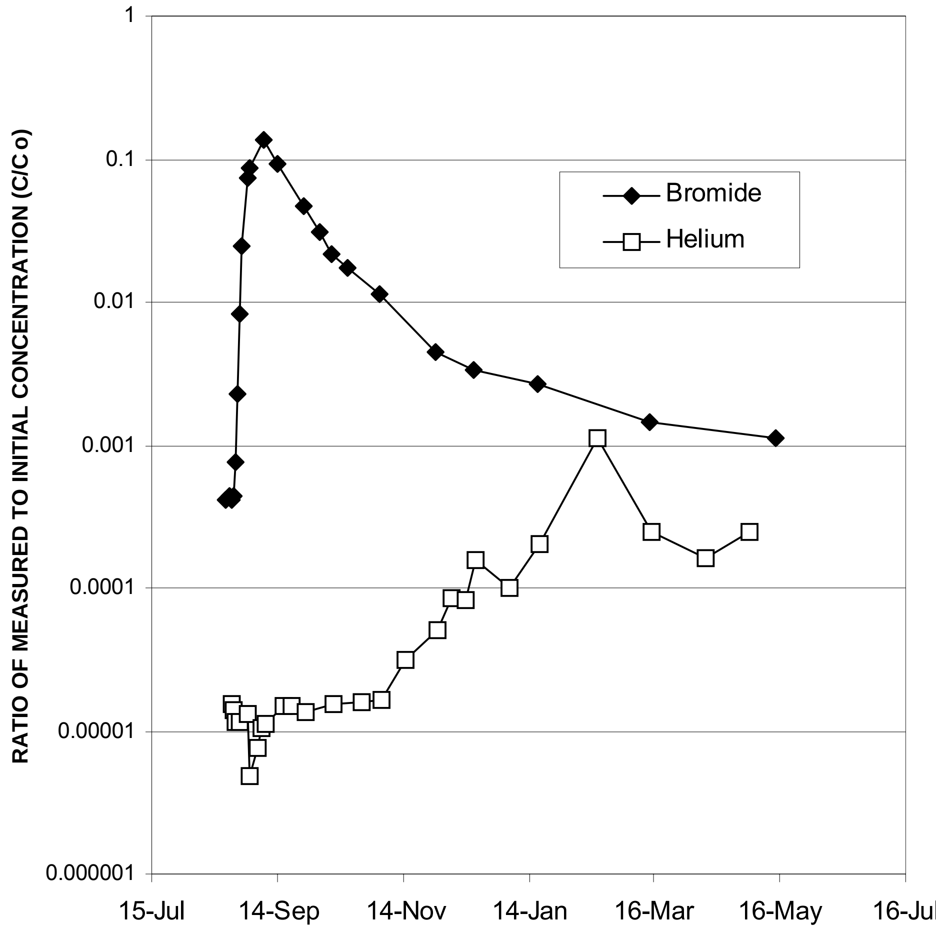

Figure 11. Retardation of helium with respect to bromide at a depth of 5.5 feet beneath the infiltration pond, Sand Hollow basin, Utah.

A previously unconsidered but potentially negative aspect of the infiltration pond experiment was the flushing of naturally accumulating unsaturated-zone salts down to the water table (figure 12). This caused dissolved-solids, nutrients, and arsenic concentrations in the ground water to temporarily exceed the State of Utah drinking water standards (Utah Department of Environmental Quality, 2001). Cross-sectional modeling indicates that these salts will rapidly be diluted in the underlying aquifer because of relatively high seepage rates and large aquifer thickness (Ludwig, 2002). However, such salt flushing from the unsaturated zone may cause substantial degradation of ground-water quality beneath arid-region artificial recharge basins with lower seepage rates and/or a thinner underlying aquifer.

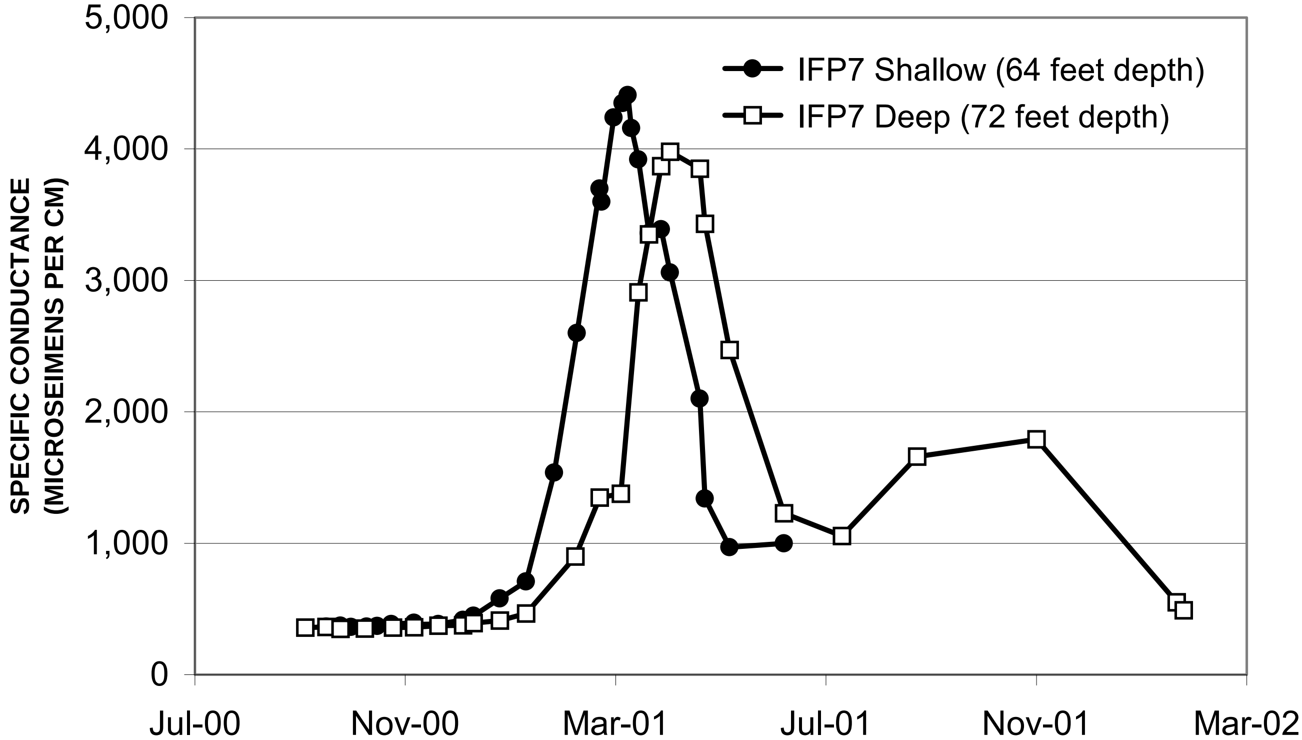

Figure 12. Increase in specific conductance of shallow ground water beneath the infiltration pond at Sand Hollow basin, Utah.

0.2	60.0	Left on North Dam access road.
3.4	63.4	Left on Highway 9.
2.3	65.7	Right on Quail Creek Reservoir road.
1.0	66.7	**Point of Interest**: Passing through axis of Virgin River anticline.
2.0	68.7	Right on I-15 frontage road.
0.3	69.0	Left under highway to Red Cliffs Recreation Area.
1.7	70.7	**STOP NO. 5**: RED CLIFFS RECREATION AREA: Lunch and optional hike along Quail Creek. Discussion Leader: Vic Heilweil, U.S. Geological Survey.

Quail Creek is one of six perennial streams within the central Virgin River basin that recharge the Navajo Sandstone aquifer as they traverse its outcrop. Seepage measurements during October 1995 indicated that about 0.2 cubic foot per second recharges the Navajo Sandstone aquifer from the creek. Figure 13 shows all potential sources of recharge to the aquifer, including the locations of these perennial streams and the amount of measured seepage loss to the underlying aquifer. Total recharge to the Navajo aquifer within the study area from perennial streams and reservoirs is estimated to be between 3 and 13 cubic feet per second (table 1, Heilweil and others, 2000).

Lunch Discussion: Recharge from Underlying Formations

Another source of recharge shown in figure 13, but not "visited" during a field trip stop is seepage from underlying formations. This form of recharge is thought to occur in two distinct areas within the central Virgin River basin: north of St. George and southwest of Hurricane (figure 13). These areas, characterized by the Utah Geological Survey as low-temperature geothermal areas (Budding and Sommer, 1986), have slightly elevated ground-water temperatures (20 to 35 degrees Centigrade) and dissolved-solids concentrations greater than 500 mg/L. The geochemical signature of these higher solute waters within the Navajo Sandstone aquifer, shown in figure 14, indicates that the source of this water is from underlying formations. Simple ground-water mixing models indicate that recharge to the aquifer from underlying formations is about 2.7 cubic feet per second north of St. George and 1.5 feet per second southwest of Hurricane (Heilweil and others, 2000).

1.7	72.4	Leave Red Cliffs Recreation Area and turn right on I-15 frontage road.
3.8	76.2	Right on Highway 9 (State St.).
1.0	77.2	Left on I-15 southbound entrance ramp.
7.3	84.5	Exit 8; Right on St. George Blvd.
2.0	86.5	Right on Bluff Street.
1.1	87.6	Left on Sunset Blvd. (old Highway 9).
11.0	98.6	Right on Gunlock Road.
4.2	102.8	Right on dirt road toward Gunlock Well #7 pump house. **STOP NO. 6A**: GUNLOCK WELL FIELD AQUIFER TEST: Discussion Leader: Vic Heilweil, U.S. Geological Survey.

During February 1996, The U.S. Geological Survey conducted a multiple-well aquifer test at St. George City Water and Power Well #7. St. George City pumped this well for 6 days at about 850 gallons per minute. The U.S. Geological Survey measured water levels at seven observation wells during the test (figure 15), but only two of these (#8 and #5) had measurable effects from the pumping (figure 16). Flumes installed in the Santa Clara River showed a decrease in flow by about 110 gallons per minute during the test. It is assumed that additional leakage to the Navajo aquifer came from the saturated fluvial sediments underlying the river. Because of this pumping-induced stream leakage and fracture-induced anisotropy, the aquifer-test data could not be analyzed with standard analytical techniques (figure 17). Rather, The U.S. Geological Survey constructed a three-dimensional ground-water flow model (figure 18) to evaluate hydraulic properties. The model indicates that the hydraulic conductivity of the Navajo Sandstone at this site is 0.3 feet per day in the east-west orientation and 1.0 feet per day in the north-south direction (Heilweil and others, 2000). Interestingly, this is perpendicular to the predominant direction of anisotropy found at the Anderson Junction aquifer test site (Stop No. 1). One limitation of the model is that the unconsolidated fluvial sediments were not included as a separate model layer.

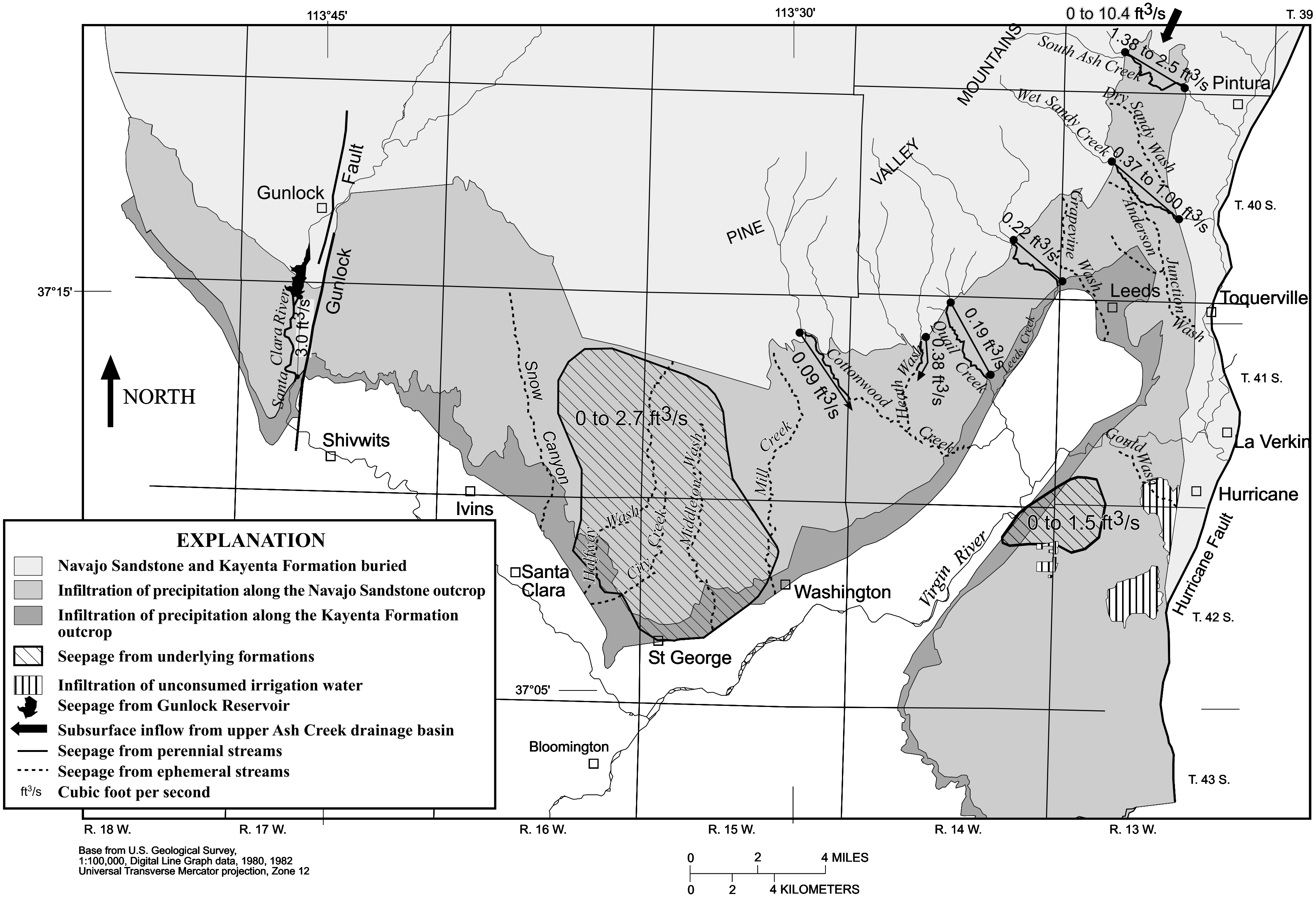

Figure 13. Potential sources of recharge to the Navajo Aquifer in the central Virgin River basin area, Utah

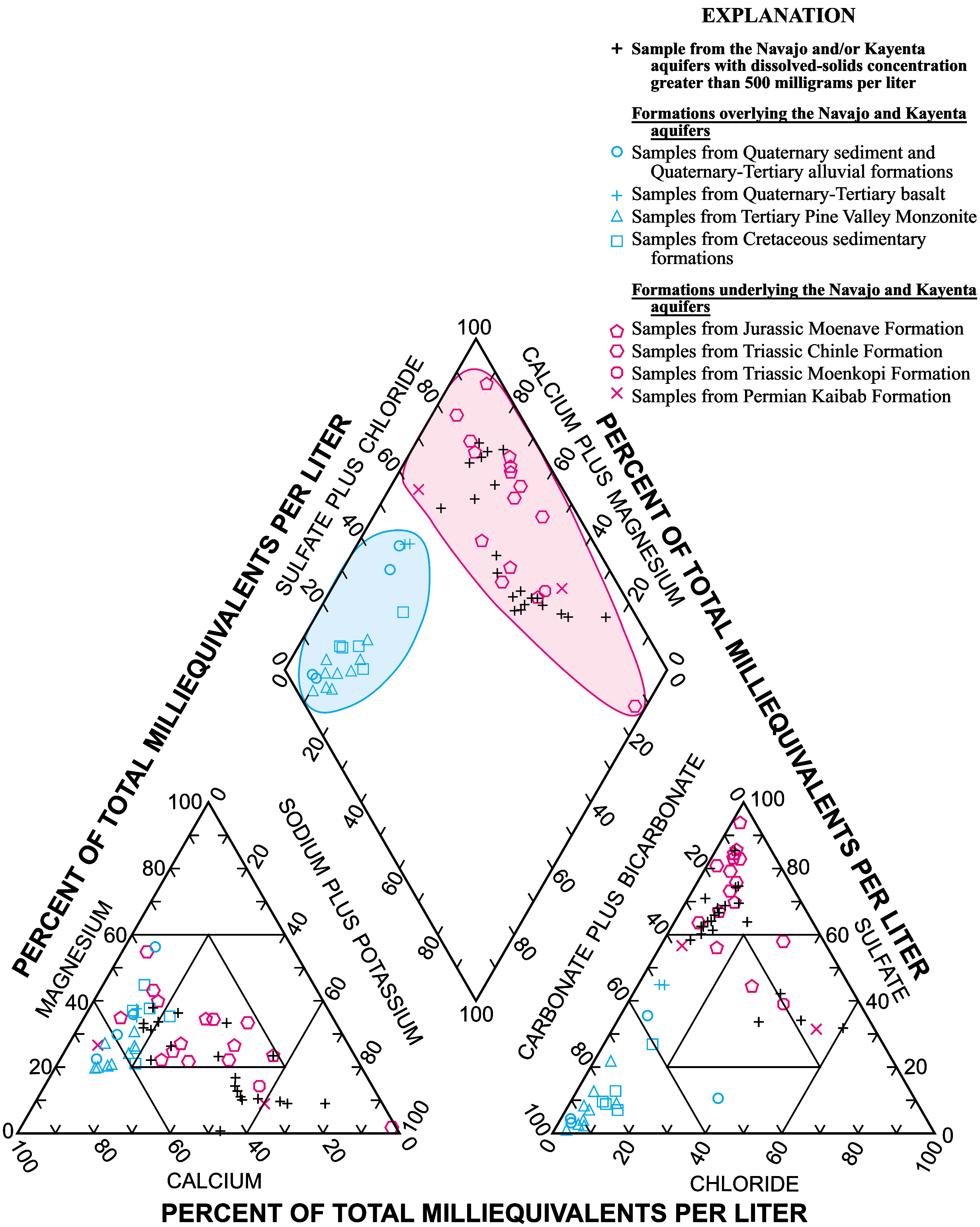

Figure 14. Relation of Navajo aquifer samples with high dissolved-solids concentration to the chemical composition of samples collected from overlying and underlying formations within the central Virgin River basin area, Utah.

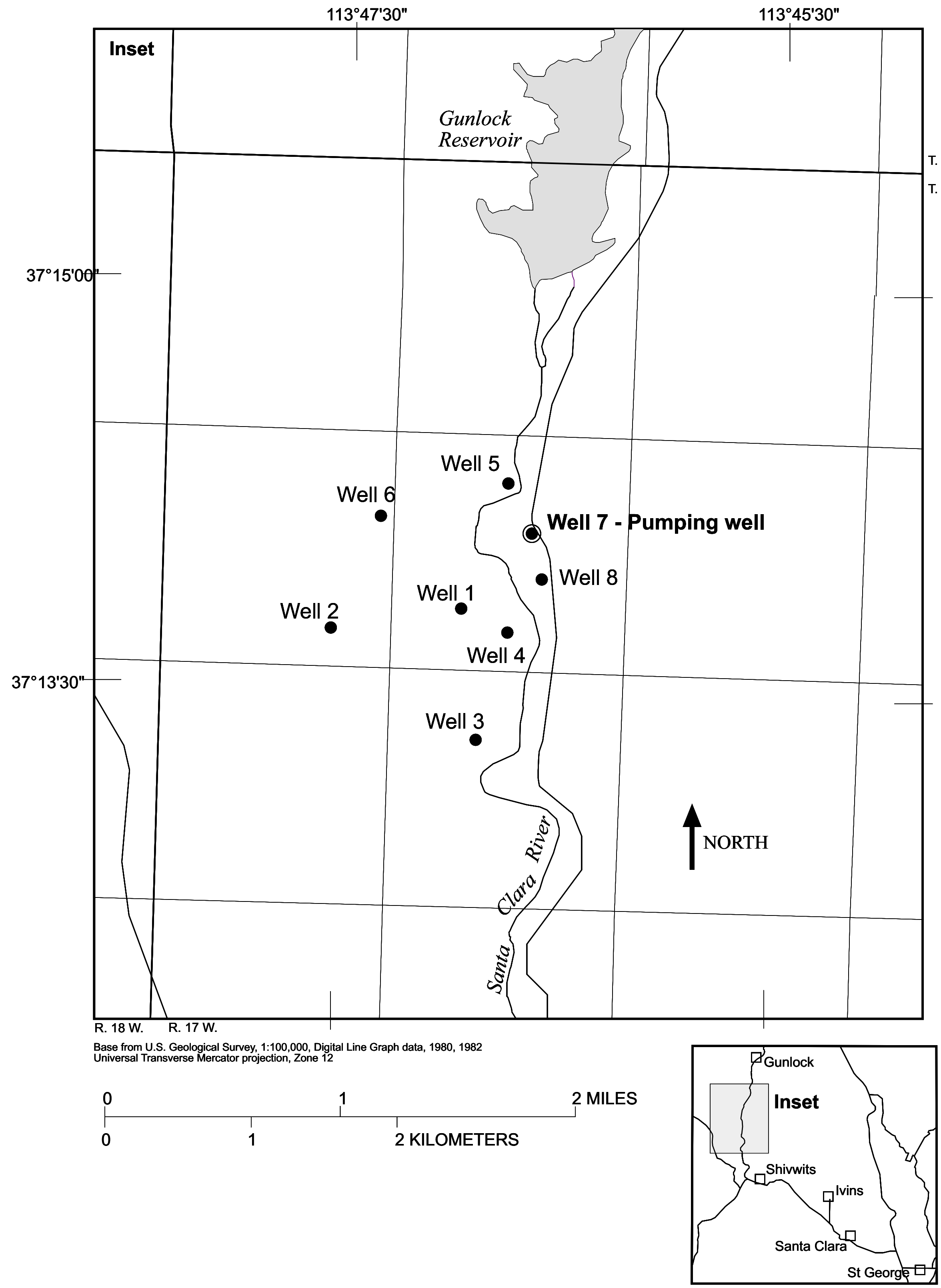

Figure 15. Location and identification of wells used for water-level measurements during the February 1996 Gunlock aquifer test, central Virgin River basin area, Utah.

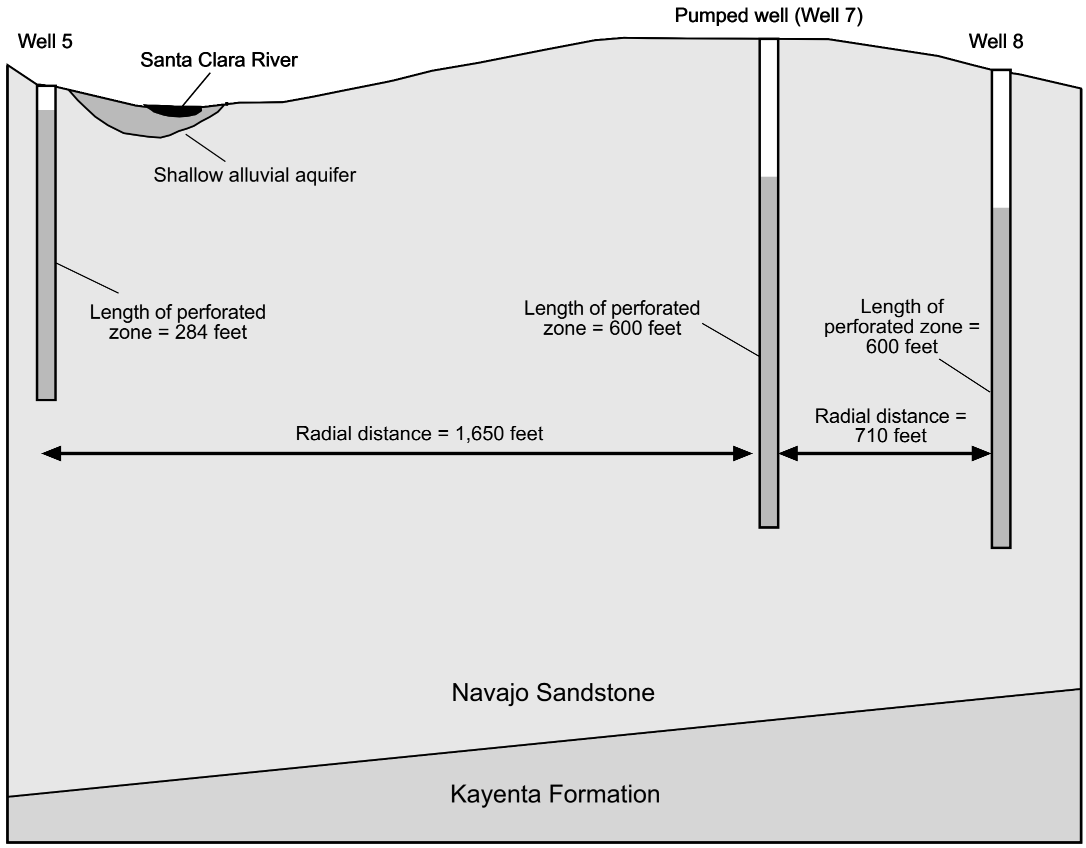

Figure 16. Generalized geologic cross section in the vicinity of the pumped well for the Gunlock aquifer test, central Virgin River basin area, Utah.

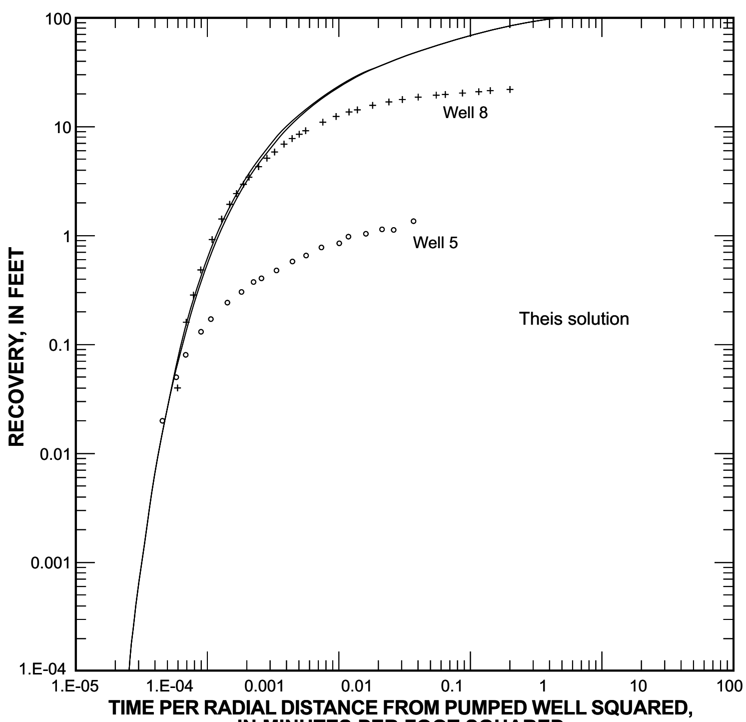

Figure 17. Theis solution fit to recovery data from two observation wells during the February 1996 Gunlock aquifer test, central Virgin River basin area, Utah.

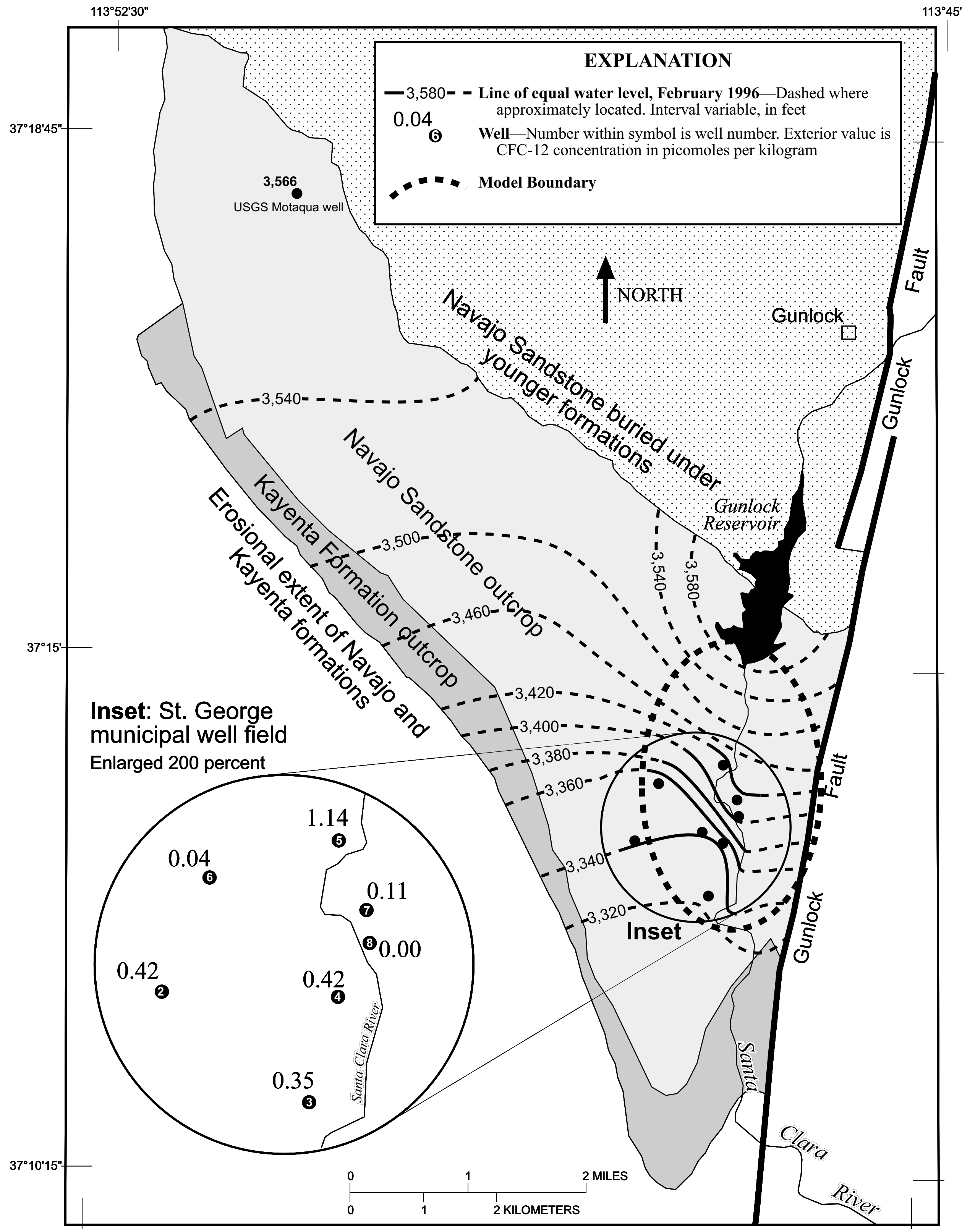

Figure 18. Aquifer-test ground-water model boundary, potentiometric contours, and chlorofluorocarbon concentrations in the Gunlock part of the Navajo aquifer, central Virgin River basin area, Utah.

0.0 102.8 **STOP NO. 6B**: SANTA CLARA RIVER: Cross road and walk down to Santa Clara River. Discussion leaders: Steve Meismer, Virgin River Recovery Program; Vic Heilweil, U.S. Geological Survey.

A seepage study along the part of the Santa Clara River traversing the Navajo Sandstone outcrop in 1974 (Cordova, 1978) found that 1.5 cubic feet per second of ground water discharged into the river, which acted as a regional drain for the aquifer. Subsequent ground-water development by the City of St. George has resulted in a reversal in hydraulic gradient, such that the Santa Clara River now loses water to the aquifer. Measurements in 1995 and 1996 indicate that between 4 and 5 cubic feet per second seeps from the river into the underlying aquifer (Heilweil and others, 2000). The amount of stream loss may increase as the amount of ground-water withdrawals continues to increase.

Comparison of ground water and Santa Clara River water chemistry also indicates that the river is the primary source of recharge for St. George City's well field. Figure 18 shows that wells downgradient of the river have fairly high CFC-12 concentrations, similar to Santa Clara River water. The presence of CFC-12 generally indicates a meteoric source of precipitation within the past 50 years (Busenberg and Plummer, 1992). Because these production wells are screened over hundreds of feet; however, the well water may be a mixture of both older and younger ground water. Except for Well No. 2, the general chemistry of the ground water is nearly identical to that of the Santa Clara River (figure 19). Well No. 2 has higher dissolved solids concentrations and a geochemical signature more similar to water from underlying formations (figure 14). This indicates that Well No. 2, which is perforated closer to the base of the Navajo Sandstone, derives some of its water from underlying formations (Heilweil and others, 2000).

To conserve surface water (protect it from seepage and evapotranspiration along the natural stream channel), a pipeline is being planned between the Gunlock Reservoir and the town of Ivins. This water savings should allow for at least 3 cubic feet per second to be released year round along the natural wash. The Virgin River Recovery Program, charged with protecting and enhancing native fish species in the Virgin River basin, is presently evaluating this amount of discharge from the reservoir to determine if it is sufficient to meet the in-stream needs of the native fish population. Part of this evaluation includes a release experiment from the Gunlock Reservoir along the Santa Clara River to determine the amount of water that needs to be released from the reservoir to maintain sufficient flow in the Santa Clara River below the Gunlock well field.

The array of piezometers at this location and two other downstream sites is part of this effort to evaluate instream flows. By monitoring water levels in the unconsolidated fluvial sediments during the release experiment, changes in storage can be evaluated for determining when seepage rates from the stream have reached steady-state conditions. The piezometers also will be used to evaluate the hydraulic connection between the river, the unconsolidated fluvial sediments, and the underlying Navajo Sandstone.

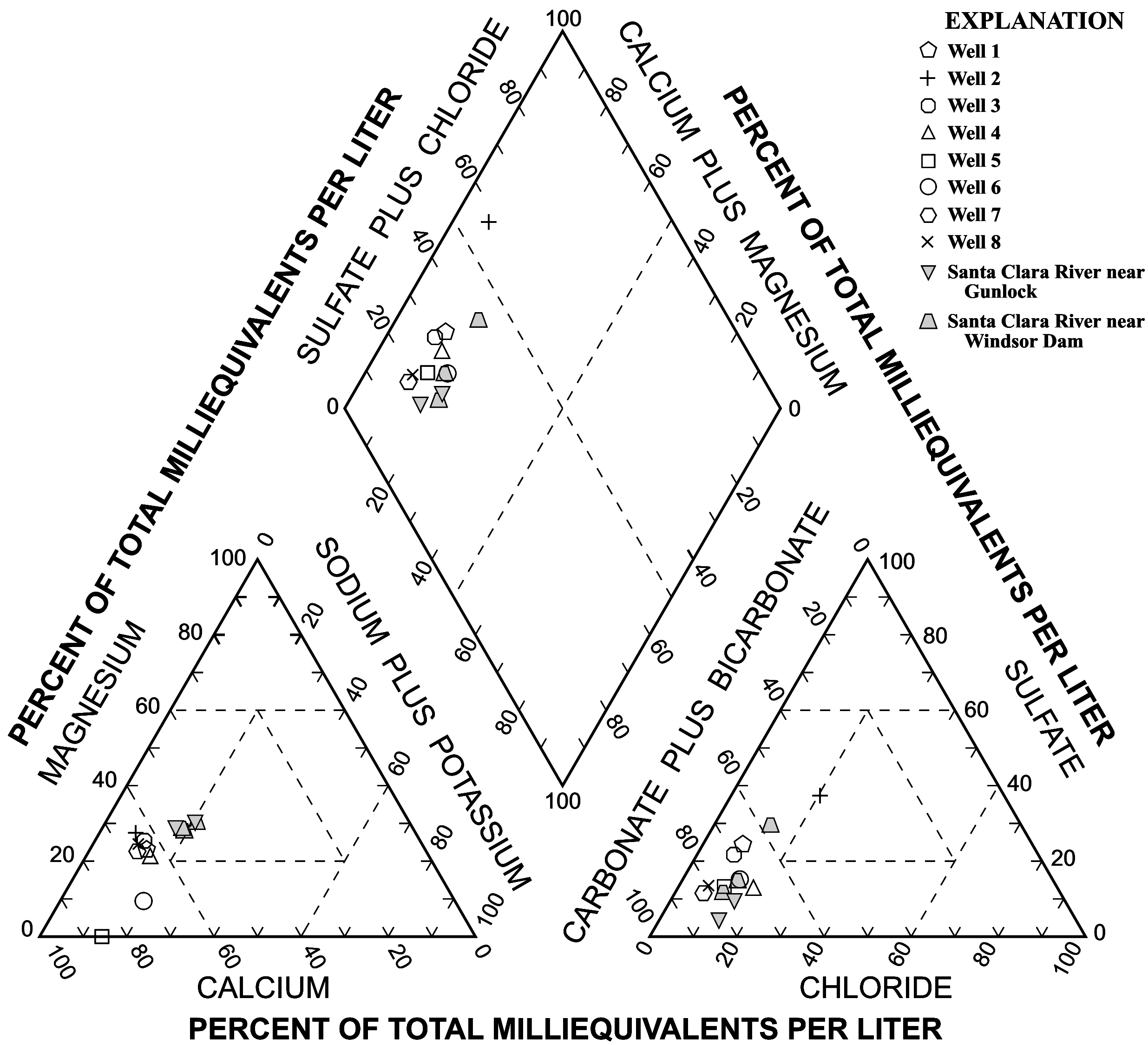

Figure 19. Geochemical comparison of Gunlock well-field ground water to Santa Clara River water, central Virgin River basin study area, Utah.

1.9	104.7	**Point of Interest**: Confluence of Sand Cove Wash with Gunlock Reservoir.
1.6	106.3	Right on gravel road at “Gunlock Town Limit” sign.
5.9	112.2	Right on dirt road toward Sand Cove.
1.0	113.2	**STOP NO. 7**: SAND COVE WASH: Discussion Leaders: David Susong, U.S. Geological Survey; Dennis Watt, U.S. Bureau of Reclamation. Note: Stop No. 7 is on private land and is not accessible to the public. An alternative spot to view Sand Cove Wash is behind the Utah Power and Light power plant on the south side of the road about 4 miles past Gunlock

Sand Cove Wash is an ephemeral wash that is presently being evaluated as a potential site for artificial recharge. About every third year, a substantial winter snow pack builds up in the Pine Valley Mountains. Spring snowmelt runoff in the Santa Clara River during these years often overflows the spillway at Gunlock Reservoir and is lost downstream. The Washington County Water Conservancy District is hoping to better utilize this snowmelt runoff by spreading some of this water into Sand Cove Wash. A series of aqueducts and pipelines currently transport water from the Santa Clara River to two Utah Power and Light power plants nearby Sand Cove Wash. This same infrastructure could be used to transport a portion of the snowmelt runoff to the wash. The Washington County Water Conservancy District hopes that most of the water put in the wash would eventually reach the Gunlock Reservoir, but be delayed by at least a month. The U.S. Bureau of Reclamation and the U.S. Geological Survey are presently evaluating the artificial recharge potential of the site, including travel times to Gunlock Reservoir. These agencies will collect data and construct ground-water flow models to evaluate the amount of water that likely will seep into the underlying Navajo Sandstone, recharging the regional aquifer. Nearby wells indicate that the depth to the Navajo aquifer water table beneath the wash is around 1,000 feet, so unsaturated-zone travel times would likely be at least decades.

1.0	114.2	Left on gravel road toward Dameron Valley.
2.2	116.4	Right on Highway 18 toward St. George.
14.2	130.6	Left on Red Cliffs Road.
2.6	133.2	Left on Skyline Road.
1.0	134.2	Right on 1000 East.
0.1	134.3	Left on St. George Blvd.
0.3	134.6	Left on northbound I-15 entrance ramp.
50.0	184.6	Exit No. 59 (central Cedar City Exit); Right on 200 North.
0.1	184.7	Right on 1150 West.
0.4	185.1	Right at parking lot near corner of 200 South and 1150 West.

END OF ROAD LOG

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