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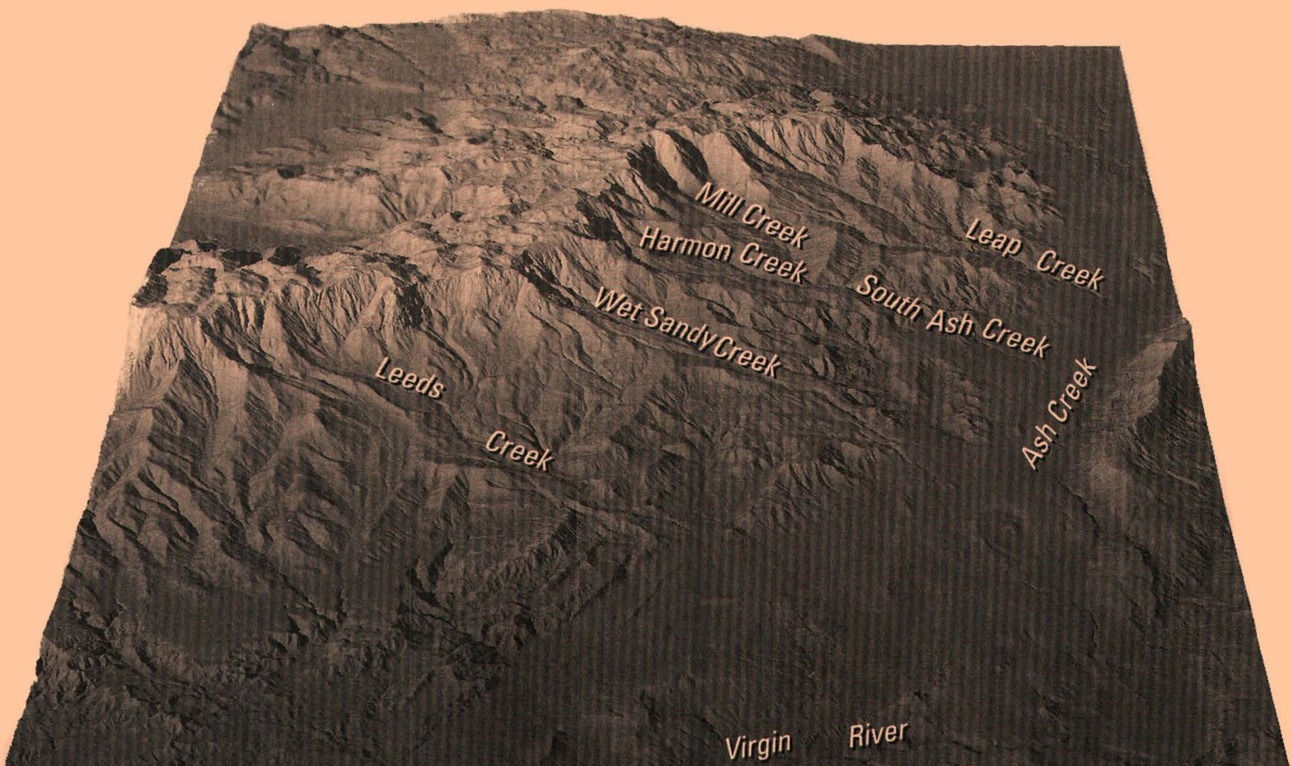
SEEPAGE INVESTIGATION FOR LEAP, SOUTH ASH, WET SANDY, AND LEEDS CREEKS IN THE PINE VALLEY MOUNTAINS, WASHINGTON COUNTY, UTAH, 1998

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 01-4237



Prepared in cooperation with the
U.S. Department of Justice and the
U.S. Department of Agriculture, U.S. Forest Service

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

Cover: Three-dimensional image of area of investigation in the Pine Valley Mountains in Washington County, Utah. View is to the north.

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Salt Lake City, Utah
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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer

Discharge is the volume of fluid that moves past a reference point per specified time interval and is reported in units of cubic feet per second (ft^3/s). One ft^3/s is equivalent to 1.9835 acre-feet per day.

Water temperature is reported in degrees Celsius (°C) and 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.

Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (μS/cm). It measures the ability of an aqueous solution to conduct an electric current.

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ABSTRACT

Seepage loss-gain data were collected along four creeks (Leap, South Ash, Wet Sandy, and Leeds) that drain the eastern flank of the Pine Valley Mountains in southwestern Utah. Streamflow was measured at a minimum of eight sites on each of the four creeks during each of three (four on South Ash) seepage investigations at higher streamflows in May and June, and at lower streamflows during August, October, and November 1998. Only two reaches on Leap and Leeds Creeks showed a significant reversal of loss or gain trends between high and low streamflow where the difference in streamflow exceeded the measurement error.

Error analyses were computed both for individual reaches between consecutive measurement sites and for composite reaches between specified, nonconsecutive measurement sites to determine if seepage losses or gains exceed the error associated with measurement of streamflow. Computed losses or gains at 31 individual reaches exceed the normalized measurement error; 16 were along channel reaches that traverse unconsolidated deposits, 7 were associated with reaches that traverse sedimentary rocks other than Navajo Sandstone, 6 were associated with reaches that traverse the Navajo Sandstone, and 2 were associated with reaches that traverse rocks of igneous origin.

Composite reaches that encompass the outcrop of one of four hydrogeologic units (Navajo Sandstone, unconsolidated deposits, igneous rocks, or sedimentary rocks other than Navajo Sandstone) were used to compute the loss or gain based on the amount measured at the upstream and downstream nonconsecutive sites. For composite reaches that traverse outcrops of Navajo Sandstone, less water was measured at (or near) the downstream contact than at (or near) the upstream contact for 11 of the 13 seepage investigations. Of those 11 investigations with computed losses, the normalized difference (N_d) was greater than the normalized error (N_e) for 6 investigations and confirms that a source of recharge to the Navajo Sandstone is seepage loss from the measured streams.

INTRODUCTION

The United States Geological Survey (USGS) was requested by the U.S. Department of Justice and the U.S. Department of Agriculture, U.S. Forest Service to collect seepage loss-gain data for four streams that drain the eastern flank of the Pine Valley Mountains (fig. 1). In addition to the collection of seepage data in an area with little or no previous hydrologic data, the data could assist water-rights adjudication issues, determination of streamflow availability, assessment of hydrologic resources, and management of Dixie National Forest. From north to south, the four creeks of interest are Leap, South Ash, Wet Sandy, and Leeds Creeks. Three separate sets of seepage investigations were done for each creek except South Ash Creek, which had four. A total of 13 investigations were completed. The first seepage investigation on each creek was completed in May and June 1998, after the diurnal fluctuations associated with snowmelt runoff had ceased but streamflow was still considerably greater than base flow. The other two seepage investigations for each creek were completed in October and November 1998, after the effects of evapotranspiration had decreased but before the onset of winter. The additional investigation on South Ash Creek was completed in August 1998 at the request of the U.S. Forest Service.

Water is, perhaps, the most valuable resource of the Pine Valley Mountains (Cook, 1957, p. 103), and wise use of this resource concerns present and future water managers and users. This seepage investigation provides data for an area where little or no previous hydrologic information has been collected. By determining the amount, timing, and location of streamflow loss (ground-water recharge) or streamflow gain

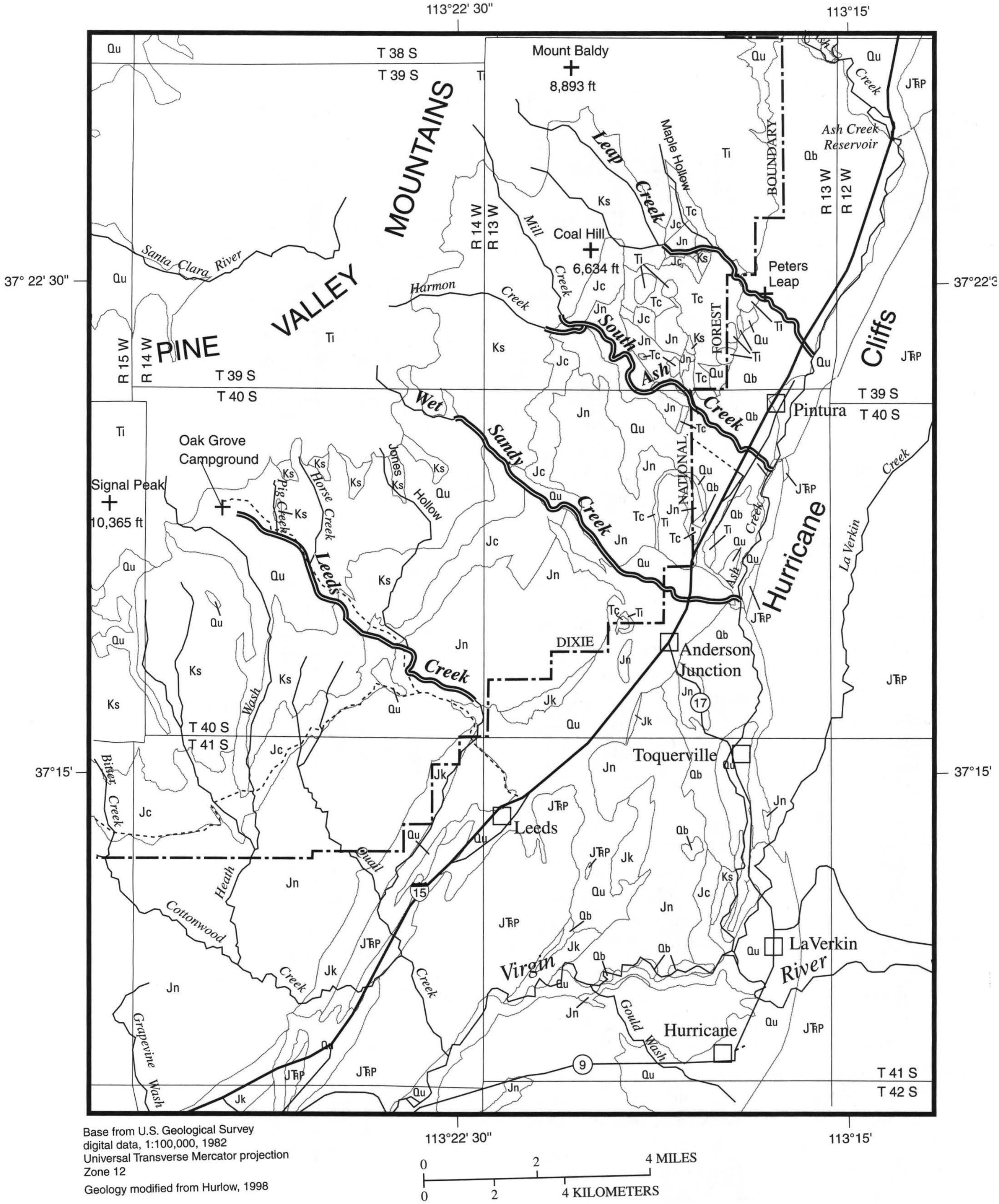


Figure 1. Location of study areas and generalized geology in Washington County, Utah.

EXPLANATION

Generalized geologic units

- Qu — Undifferentiated unconsolidated deposits of Quaternary Period
- Qb — Basalt flows of Quaternary Period
- Ti — Intrusive igneous rocks of Tertiary Period
- Tc — Claron Formation of Tertiary Period
- Ks — Undifferentiated rocks of Cretaceous Period
- Jc — Carmel Formation of Jurassic Period
- Jn — Navajo Sandstone of Jurassic Period
- Jk — Kayenta Formation of Jurassic Period
- JTRP — Older rocks of Jurassic, Triassic, and Permian Period

Study area along reaches of four creeks

Paved road

Unpaved road

Figure 1. Location of study areas and generalized geology in Washington County, Utah—Continued.

(ground-water discharge), an assessment can be made as to whether the amount of loss or gain varies temporally and spatially. Additionally, a determination can be made whether loss-gain results are related to geologic features such as rock formation or density and orientation of fractures in fault zones.

Seepage data collected in October 1995 by the USGS during a reconnaissance of the water resources of the Navajo Sandstone aquifer indicated that streamflow in South Ash, Wet Sandy, Cottonwood, and Quail Creeks infiltrates into the Navajo Sandstone where the streams cross the outcrop and that loss or gain in streamflow for Leeds Creek was within measurement error (Wilkowske and others, 1998, p. 52-53).

Purpose and Scope

The purpose of this report is to (1) present streamflow, temperature, and specific-conductance data collected during seepage investigations on Leap, South Ash, Wet Sandy, and Leeds Creeks during May, June, August, October, and November 1998; (2) compute the amount of loss or gain for specific reaches along each creek; and (3) identify possible factors such as rock formation or faults and fractures that could influence or control the amount, timing, and location of seepage losses or gains along the channels of the four drainages.

A seepage investigation involves measurement of streamflow at two or more locations along a stream to determine if it loses or gains water in that reach. More than 180 measurements of streamflow or observations of no flow were collected at 53 sites during 13 individual seepage investigations along 4 creeks (Leap, South Ash, Wet Sandy, and Leeds) in 1998 to determine the amount, timing, and location of streamflow losses (ground-water recharge) or streamflow gains (ground-water discharge). The numbering system for hydrologic-data sites used in Utah is shown in figure 2.

An error analysis was developed to quantify the significance of the computed losses and gains by determining whether those losses or gains exceeded the error associated with measurement of streamflow. Error analyses were done for individual reaches using streamflow measurements at consecutive sites and for composite reaches that used measurements of streamflow at non-consecutive sites at the beginning and end of a given reach. An error analysis for composite reaches was used to assess the importance of the four hydrogeologic units common to each creek. An estimate of the amount of streamflow loss or gain can be incorporated into water-budget estimates. Evaluation of the spatial and temporal distribution of streamflow losses or gains can help assess the relative importance of rock formation or fractures and faults.

Description of Study Area

Leap, South Ash, Wet Sandy, and Leeds Creeks drain an area of the eastern Pine Valley Mountains in southwestern Utah (fig. 1) within a geologic transition zone between the structurally more stable Colorado Plateau physiographic province to the east and the extensionally deformed Basin and Range province to the west (Scott and Swadley, 1995, p. 2). The four creeks originate at the higher altitudes of the Pine Valley Mountains, where igneous rocks of the Pine Valley laccolith crop out, and traverse faulted and folded sequences of igneous rocks and progressively older sedimentary rocks as they flow southeastward toward their confluence with Ash Creek or, for Leeds Creek, toward Quail Creek near the town of Leeds. Ash Creek flows south in the Hurricane Fault zone, which is between the eastern Pine Valley Mountains to the west and the Hurricane Cliffs to the east, and flows into the Virgin River north of Hurricane (fig. 1).

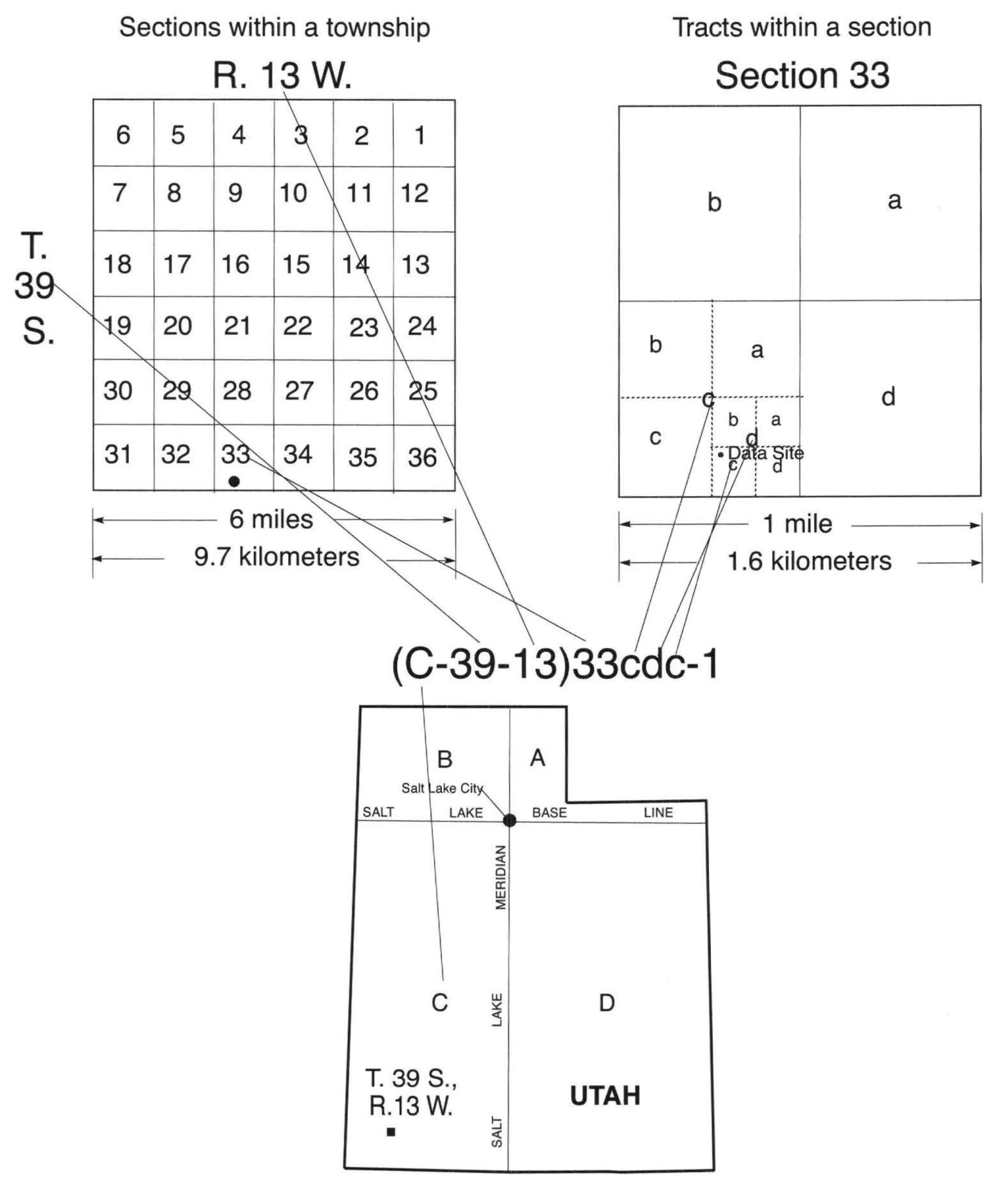
The study area is along the channels of the four creeks where data were collected. Altitude in the general area ranges from about 3,660 ft at the confluence of Wet Sandy Creek with Ash Creek to 10,365 ft atop Signal Peak, the highest point in the Pine Valley Mountains. Relief for individual channels in the study area had the following altitude range as determined from the highest streamflow-measurement site to the lowest: Leap Creek 5,240 ft to 4,180 ft; South Ash Creek 5,600 ft at the upper streamflow-measurement site on Harmon Creek to 4,160 ft; Wet Sandy Creek 6,120 ft to 3,660 ft; and Leeds Creek 6,460 ft near the Oak Grove Campground to 4,000 ft.

Geology

The geologic history of the Pine Valley Mountains is described by Cook (1957) and more recently refined by Hacker (1998). Hurlow (1998) compiled geologic maps and cross sections and discussed the structure of the study area. Rocks that crop out along any of the four creeks include sedimentary rocks deposited in a variety of environments, including fluvial (Kayenta Formation), eolian (Navajo Sandstone), and shallow marine (Temple Cap and Carmel Formations) during the Jurassic Period, and braided fluvial, flood-plain, and marine environments (undifferentiated Creta-

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 the site, describes its position in the land net. The land-survey system divides the State of Utah into four quadrants by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, that indicate, respectively, the northeast, northwest, southwest, and southeast quadrants. The upper case letter C indicates that the township is south of the Salt Lake Base Line and the range is west of the Salt Lake Meridian. Numbers that designate 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 that indicate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres for a regular section[1].

The lowercase 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 or spring within the 10-acre tract. Thus, (C-39-13)33cdc-1 designates a data site located in the southwest 1/4 of the southeast 1/4 of the southwest 1/4 of section 33, Township 39 South, and Range 13 West of the Salt Lake Base Line and Meridian.



[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular in size and shape. 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. Diagram showing numbering system used for hydrologic-data sites in Utah.

ceous Formations) during the Cretaceous Period. Thrust faulting and folding during the Sevier orogeny in the Late Cretaceous Period and warping during the Laramide orogeny in latest Cretaceous and early Tertiary Periods (Rowley and others, 1979, p. 14) followed the deposition of the undifferentiated Cretaceous Formation and created some of the major fold structures exposed in the Hurricane Cliffs between Ash Creek Reservoir and Anderson Junction. Erosion of the Laramide uplifts produced conglomerate deposits in areas northeast of the Pine Valley Mountains (Goldstrand and Mullett, 1997) that preceded fluvial and lacustrine deposition of the early Paleocene to Eocene-age Claron Formation in internally drained basins in the Pine Valley Mountains area (Feist and others, 1997, p. 30). Explosive eruption of ash-flow tuff and lava flows from nearby stratovolcanoes and calderas occurred during the Oligocene and Miocene Epochs. Subsequent emplacement of the Pine Valley laccolith (McKee and others, 1997, p. 243, 246, 249) and comagmatic eruptive suites (21 million years ago (Ma)), volcanic eruption of basalt and rhyolite flows (15 Ma to recent), basin-range extension, and associated displacement along the Hurricane Fault zone (10 Ma to recent) have been accompanied by uplift and erosion. Unconsolidated alluvial-fan and debris-flow deposits of late Tertiary and Quaternary age are found at higher altitudes of the Pine Valley Mountains and record older erosional episodes. These older deposits have been eroded and incised by stream channels and truncated at their distal end by recent offset in the Hurricane Fault zone. Younger Quaternary-aged unconsolidated deposits are at lower altitudes along stream channels and conform to present topography within the Hurricane Fault zone where they thinly cover bedrock outcrops. Geologically, both units have similar depositional characteristics (poorly sorted alluvial-fan and debris-flow deposits) and are referred to in tables and discussions in this report as undifferentiated unconsolidated deposits of Quaternary age.

More recently, as a result of uplift or faulting and attendant changes to base level, the creeks have incised their channels into the older unconsolidated deposits and, in places, into the underlying sedimentary, intrusive, or basaltic rocks. South Ash Creek is an example of a recently incised canyon where the channel is entrenched into the Navajo Sandstone in a narrow, 400-ft-deep gorge. Leap and Wet Sandy Creeks also have incised channels in the Navajo Sandstone, though less deeply than South Ash Creek has. Leap Creek has carved a 200-ft-deep box canyon into Quaternary-aged basalt flows from Peters Leap to just west of I-15.

On the basis of similar hydrologic characteristics, the geologic rock units are grouped into four hydrogeologic units that are common to each creek. The four hydrogeologic units are (1) Navajo Sandstone, which is composed of fine-grained eolian sandstone; (2) undifferentiated, unconsolidated, and poorly sorted Quaternary-age alluvial-fan and debris-flow deposits; (3) igneous rocks that include the intrusive Pine Valley laccolithic rocks of Tertiary age and the extrusive basalt flows of Quaternary age; and (4) sedimentary rocks other than the Navajo Sandstone that include the Carmel Formation, undifferentiated Cretaceous-age rock, and the Claron Formation. The saturated parts of the Navajo Sandstone and Kayenta Formation provide most of the potable water to the municipalities of Washington County (Heilweil and others, 2000, p. 45).

Climate

Climatic types in the area range from steppe or semiarid at lower altitudes to undifferentiated highland at the higher altitudes of the Pine Valley Mountains (Murphy, 1981, p. 55). Steppe or semiarid climates occur when annual precipitation is greater than one-half of the annual potential evapotranspiration, which for most of the study area in the eastern Pine Valley Mountains ranges from 21.0 to 29.9 in. (Richardson and others, 1981, p. 65), and occur between the desert margins and the higher mountain regions (Murphy, 1981, p. 55). Undifferentiated highland climate occurs where annual precipitation exceeds potential evapotranspiration. Potential evapotranspiration averages less than 20.9 in. per year (Richardson and others, 1981, p. 65) at the higher altitudes of the Pine Valley Mountains. Estimated normal annual precipitation (1961-90) on the eastern Pine Valley Mountains ranges from 12 in. at Leeds to 30 in. at Signal Peak (Utah Climate Center, 1996). There are no weather stations in the study area; the nearest stations are at New Harmony (about 2 mi north of the northern margin of fig. 1) and LaVerkin (fig. 1). New Harmony, at an altitude of 5,265 ft, received an average of 18.23 in. per year; and LaVerkin, at an altitude of 3,220 ft, received an average of 11.17 in. per year for the 1961-90 normal period. For water year 1998, however, precipitation was 20.49 and 15.45 in. at New Harmony and LaVerkin, respectively, or 2.26 in. and 4.28 in. greater than normal. For October 1998, New Harmony received 2.08 in. and LaVerkin 1.12 in., compared to a normal monthly amount of 1.17 and 0.69

in., respectively. Interpretation of the data collected during this investigation should take into account the fact that the winter 1997-98 snowpack, and the May, June, September, and October 1998 monthly precipitation totals were greater than normal.

Vegetation in the study area includes sagebrush, pinyon, and juniper at the lowest altitudes. Oakbrush and manzanita brush dominate the mid-altitudes, and isolated stands of spruce and fir grow in the higher altitudes of Leeds Creek at Oak Creek Campground. Some deciduous trees and phreatophytes grow along the stream channels that provide reliable sources of water.

Acknowledgments

Thanks to Andrew Walch, U.S. Department of Justice, Environment and Natural Resources Division; Hugh Thompson, former Dixie National Forest Supervisor; Dale Torgerson, former U.S. Forest Service Regional Water Strategy Team Leader; and Kelly Shanahan, former Dixie National Forest Hydrologist; for recognizing the importance of hydrologic data as a basis for any management decision.

METHODS OF STUDY

Seepage investigations are an effective tool to determine the interaction between surface water and ground water. To accurately determine the amount of seepage loss or gain, streamflow is measured at several cross sections along a channel reach. Each cross section constitutes a streamflow-measurement site that is located within the stream channel and perpendicular to the direction of water movement where the width, depth, and velocity of water is measured. A reach is a horizontal distance along a stream channel and can refer either to the individual reach between consecutive streamflow-measurement sites or the composite reach between nonconsecutive streamflow-measurement sites. Amount, timing, and location of computed streamflow losses or gains are combined with observations about the rock formations that crop out along a stream reach and fault or fracture density to determine the factors that could influence the distribution of losses or gains.

In this report terms such as losses and gains are reserved for surface-water discussions and ground-water recharge and ground-water discharge refer to the ground-water system. Seepage refers to the amount of water lost or gained in a specified individual or composite reach. Streamflow, or discharge, is the volume rate of fluid that passes a reference point with respect to time (Chow, 1964, p. 7-9; Rantz and others, 1982, p. 79) and is reported in cubic feet per second (ft^3/s).

Streamflow was measured at a minimum of eight sites on each of the four creeks during each of three (four on South Ash Creek) seepage investigations. Streamflow-measurement sites were selected to divide each reach into equal lengths or were located at the ends of specified bedrock outcrops. Tributary inflows and diversion outflows were measured where they occurred. If a site had more than one measurement of streamflow during an individual seepage investigation, then the average of those measurements is used. Total lengths of each reach studied are: Leap Creek 20,380 ft, South Ash Creek 27,690 ft, Wet Sandy Creek 35,760 ft, and Leeds Creek 33,690 ft. Access restrictions limited the placement of the uppermost streamflow-measurement site on Leap and Wet Sandy Creeks. Investigations on three creeks were terminated where the creeks flow into Ash Creek. The investigations on Leeds Creek were terminated at the USGS gage about 2 mi north of Leeds (fig. 1) and upstream of Leeds Diversion.

Streamflow loss or gain is determined by subtracting the sum of the streamflow measured at a consecutive upstream site (Q_{us}) and the streamflow measured at any tributary inflow (+ Q_{inflow}, plus) and diversionary outflow (- $Q_{diversion}$, minus) from the streamflow measured at a downstream site (Q_{ds}). If the streamflow at the downstream site is more than the sum of the upstream streamflow and any intervening inflows or diversions, then a computed gain is determined for the intervening reach. Conversely, if the streamflow at the downstream site is less than the sum of the upstream streamflow and any intervening inflows or diversions, then a losing reach is computed. For example:

$$\text{Computation of Loss (-) or Gain (+)} = Q_{ds} - (Q_{us} + Q_{inflow} - Q_{diversion}) \quad (1)$$

Normalized percentage difference is determined for streamflow measured at consecutive measurement sites along a channel reach. Seepage losses or gains are normalized to the maximum streamflow measured at consecutive measurement sites plus inflows and diversions:

$$(N_d\%) = \frac{Q_{ds} - (Q_{us} + Q_{inflow} - Q_{diversion})}{MaxQ_{(us + inflow, ds + diversions)}} \bullet 100 \quad (2)$$

where:

Q_{ds} = streamflow measured at a downstream measurement site;

Q_{us} = streamflow measured at an upstream measurement site;

Q_{inflow} = streamflow of any inflow;

$Q_{diversion}$ = streamflow of any diversion;

$Max\ Q_{(us+inflow,\ ds+diversions)}$ = maximum streamflow measured at consecutive upstream or downstream sites. For special cases, tributary inflows are added to the upstream streamflow and diversions are added to the downstream streamflow to determine the maximum streamflow; and

100 = conversion to percentage.

The $N_d\%$ ranges from 0 percent, when Q_{ds} and Q_{us} are equal, to +/- 100 percent, when either Q_{ds} or Q_{us} is zero. When $N_d\%$ approaches +/- 100 percent, one of the two consecutive sites is dry or nearly dry, a condition that occurs when all water in the creek is diverted or lost to seepage.

Normalized percentage error ($N_e\%$) is calculated to determine if a computed loss or gain significantly exceeds errors associated with current meter streamflow measurements and is normalized to the maximum streamflow of two consecutive streamflow-measurement sites plus inflows and diversions.

$$(N_e\ \%) = \pm \left[\frac{(aQ_{us} + aQ_{ds} + aQ_{inflow} + aQ_{diversion})}{MaxQ_{(us\ +\ inflow, ds\ +\ diversions)}}\right] \bullet 100 \quad (3)$$

where:

a = accuracy of a streamflow measurement, ranges 0.05 for good, 0.08 for measurements rated fair, and greater than 0.08 for measurements rated poor;

Q_{us} = streamflow measured at upstream site;

Q_{ds} = streamflow measured at downstream site;

Q_{inflow} = streamflow of any inflow;

$Q_{diversion}$ = streamflow of any diversion;

$Max\ Q_{(us+inflow,\ ds+diversions)}$ = maximum streamflow measured at consecutive upstream or downstream sites. For special cases, tributary inflows (either from tributaries or return flows from diversions) are added to the upstream streamflow and diversions are added to the downstream streamflow to determine the maximum streamflow; and

100 = conversion to percentage.

If Q_{ds} is greater than Q_{us}, then sign is plus (+) and signifies a gain. Conversely, if Q_{ds} is less than Q_{us}, then sign is minus (-) and signifies a loss. If one streamflow-measurement site is dry, i.e., Q_{us} or Q_{ds} equals 0, then the maximum error ranges from 5 percent (for a measurement rated good) to more than 8 percent (for a measurement rated poor) of the measured streamflow. If $Q_{ds} = Q_{us}$, then the maximum error ranges from 10 percent to 16 percent. A computed loss or gain of a reach is considered significant when the normalized difference ($N_d\%$) is equal or greater than the normalized error ($N_e\%$). This determination of significance is called an error analysis. The error analysis was computed for individual reaches by using measurements of streamflow at consecutive sites and for composite, nonconsecutive sites.

Seepage investigations typically are done during periods of base flow (Riggs, 1972, p. 12) when losses or gains to streamflow are attributable to recharge or discharge from the ground-water system and not attributable to runoff from precipitation or snowmelt. This investigation purposely measured streamflow during nonbase-flow periods to determine if losses or gains were consistent at both high flows and base flows. One seepage investigation on each of the four streams was done in May or June 1998 when streamflows were elevated by runoff from a greater-than-average snowpack but after the daily streamflow flucuations associated with snowmelt runoff had moderated or ceased. Two seepage investigations for each creek were done in October and November 1998 after the effects of evapotranspiration had decreased and at flows more typical of base flow. An additional investigation on South Ash Creek was done in August 1998 at the request of the U.S. Forest Service.

Hydrologic conditions that determine whether a creek loses water to the aquifer or gains water from the aquifer relate to the relative altitude of the water table in the vicinity of the creek. When the stage (or gage height) in a creek is higher than the water level in the aquifer, the potential exists for water in the creek to lose water, which can recharge the aquifer. When the water level in the aquifer is higher than the stage in a creek, the potential exists for the creek to gain water, which can be derived from discharge of water from the aquifer to the creek. For both conditions to occur, the intervening material that separates the creek and aquifer must have the ability to transmit water. A rock material's ability to transmit water is a function of the interconnectiveness of the water-conducting pore space in the rock material. These transmissive properties are either enhanced or reduced by faults, fractures, and joints.

Three of the four creeks studied have an active USGS streamflow-gaging station. A discontinued gage on South Ash Creek was reactivated for 6 months to collect gage-height data. These gages record gage-height data every 15 minutes and were used to determine if flow conditions were stable enough to perform a seepage investigation and to monitor gage heights during each seepage investigation. Leap and Wet Sandy Creeks were equipped with satellite-transmitting capabilities so that nearly real-time gage-height data could be viewed in the office to determine whether the stage was stable enough to initiate a seepage investigation.

Measurements of streamflow for this investigation used either pygmy or Price AA current meters and explicitly follow USGS guidelines and procedures specified by Rantz and others (1982). Observations of width, depth, and velocity at 25 or more intervals, if possible, define a cross section that is perpendicular to the direction of flow. Minimum width intervals are 0.2 ft for a pygmy meter and 0.4 ft for a Price AA meter. When depths are less than 1.5 ft for a pygmy meter or less than 2.5 ft for a Price AA meter, velocity is determined at a single depth that is six-tenths of the total depth below water surface. When depths exceed 1.5 ft for a pygmy meter or 2.5 ft for a Price AA, two velocity observations are determined at two-tenths and eight-tenths of the total depth below the water surface. A mean velocity is derived from averaging velocity from both observations. Even for experienced hydrographers who use properly maintained and calibrated equipment, there are inherent errors associated with streamflow measurements that relate to the physical characteristics of the channel and the pulsatic nature of natural open-channel flow. For this seepage investigation, the shallow depths of the creeks often affected how closely a measured streamflow compared to the "true" streamflow. Where total depths are shallow, generally less than 0.75 ft when using a Pygmy current meter and less than 1.25 ft when using a Price AA current meter, the respective meters are within 0.3 ft and 0.5 ft of the streambed and friction generated by the channel bed causes the velocity to be underestimated (Rantz and others, 1982, p. 135, 144). Pulsation errors are minimized by measuring the velocity in any given vertical profile for 40 seconds or longer (Sauer and Meyer, 1992, p. 11-12). The accuracy of the streamflow measurements reported herein generally is rated as good, fair, or poor, which means in the opinion of the streamgager that the measured streamflow is within 5 percent, 8 percent or greater than 8 percent, respectively, of the"true" streamflow. Two estimates of streamflow were considered to be within 25 percent of the "true" discharge.

RESULTS OF SEEPAGE INVESTIGATIONS

The results and interpretation of the seepage investigations for each creek are discussed in the order of the creeks from north to south. Streamflow, specific conductance, and temperature data are presented in tables 1, 3, 5, and 7; graphs showing gaining and losing reaches along the four creeks are shown in figures 4, 6, 8, and 10. Tables of calculated normalized percentage difference and normalized percentage error are presented in tables 2, 4, 6, and 8, and are included with the discussion for each creek.

Leap Creek

Three seepage investigations were completed on May 29, October 13, and October 29, 1998, along a 20,380-ft reach of Leap Creek (table 1) that extends from Coal Hollow to the confluence of Leap Creek and Ash Creek (fig. 3). Of the four creeks studied, Leap Creek traverses the most complexly faulted terrain (Cook, 1957, fig. 10, p. 25; Hurlow, 1998, pl. 1). Mapped fault zones trend predominantly north-northeast in southwestern Utah (Rowley and others, 1979, p. 15-16).

Streamflow variation on May 29 resulted from melting of the considerable snowpack during the day. At night convective cooling reduced snowmelt. Gage heights recorded at 15-minute intervals at USGS streamflow-gaging station 09406640 (Leap Creek below Maple Hollow, near Pintura) dropped 0.02 ft during the 6 hours required to complete the May 29 seepage investigation. Gage heights on October 13 and October 29 fluctuated 0.02 and 0.01 ft, respectively.

The upper measurement site on Leap Creek near Coal Hollow was at a faulted contact of the Navajo Sandstone and Carmel Formation (Hurlow, 1998, pl. 1). Immediately downstream, the Navajo Sandstone crops out for a distance of about 3,900 ft in a narrow, steeply incised 200-ft-deep gorge. Except for the last 1,000 or so feet of the 4,920-ft reach between LP 1.0 and LP 3.0 at USGS streamflow-gaging station 09406640 (fig. 3), Leap Creek flows in a canyon carved into the Navajo Sandstone. The amount of water lost between LP 1.0

Table 1. Measurements of streamflow, specific conductance, and temperature of water from Leap Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah

[—, no data available; Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone; Qb, Quaternary basalt flows; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement including material from debris flows; Ti, Tertiary Pine Valley laccolithic intrusive rocks; Tc, Tertiary Claron Formation; ft, feet; mi, mile]

Site ID: Informal site designation: LP 1.0, whole number designation indicates the measurement site on Leap Creek main channel, ascending in downstream order; LP 2.8, even decimal number indicates tributary inflow that enters Leap Creek between main channel measurement sites at LP 2.0 and LP 3.0; LP 3.3, odd decimal number indicates outflow (diversion) between main channel measurement sites at LP 3.0 and LP 4.0.

Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.

Description of site: General description of streamflow-measurement site. USGS, United States Geological Survey; 09406640, number of streamflow-gaging station operated by the USGS.

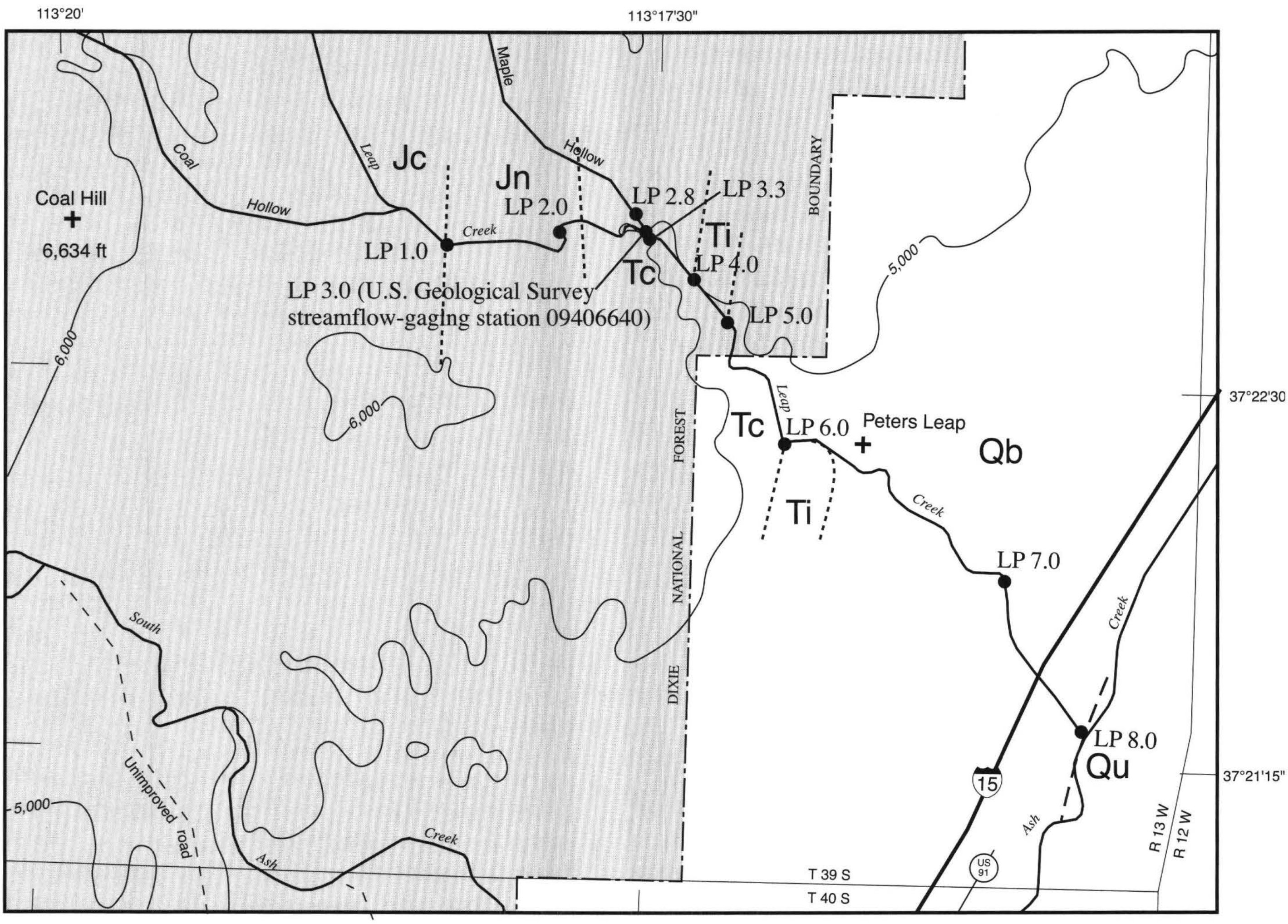
Streamflow: ft^3/s, cubic feet per second; dry, no flow.

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

Temperature: °C, degrees Celsius.

Remarks: GH, gage height of USGS gage at indicated military time; Q, measurement of streamflow.

Site ID	Location	Description of site	Streamflow (ft^3/s)	Specific conductance (μS/cm)	Temperature (°C)	Remarks
		First seepage investigation, May 29, 1998				
LP 1.0	(C-39-13)22cbc	Leap Creek below small tributary inflow below Coal Hollow	6.63	260	10.0	Jc/Jn
LP 2.0	(C-39-13)22caa	Leap Creek at first trail crossing at midpoint of Jn outcrop	—	—	—	Jn, no measurement
LP 2.8	(C-39-13)22dab	Maple Hollow inflow above USGS gage	.59	—	18.5	Tc
LP 3.0	(C-39-13)22dab	Leap Creek at USGS gage (09406640)	6.02	—	10.0	Tc; GH = 4.12 ft at 1000 hours
LP 3.3	(C-39-13)22dab	Diversion from Leap Creek below USGS gage	dry	—	—	Tc
LP 4.0	(C-39-13)23cbc	Leap Creek above Tc-Ti contact	5.96	—	11.5	Tc/Ti
LP 5.0	(C-39-13)23ccd	Leap Creek below Ti-Tc contact	6.00	—	12.5	Ti/Tc
LP 6.0	(C-39-13)26bda	Leap Creek at Tc-Ti contact near Peters Leap	7.12	290	14.5	Tc/Ti
LP 7.0	(C-39-13)25cdb	Leap Creek 0.5 mi above I-15 at tributary inflow from north	7.33	285	11.0	Qb
LP 8.0	(C-39-13)36acc	Leap Creek 75 ft above confluence with Ash Creek	5.79	285	13.0	Qb/Qu
		Second seepage investigation, October 13, 1998				
LP 1.0	(C-39-13)22cbc	Leap Creek below small tributary inflow below Coal Hollow	.79	350	9.0	Jc/Jn
LP 2.0	(C-39-13)22caa	Leap Creek at first trail crossing at midpoint of Jn outcrop	.77	360	10.5	Jn, first measurement at site
LP 2.8	(C-39-13)22dab	Maple Hollow inflow above USGS gage	dry	—	—	Tc
LP 3.0	(C-39-13)22dab	Leap Creek at USGS gage (09406640)	.68	360	9.0	Tc; GH = 3.60 ft at 1100 hours
LP 3.3	(C-39-13)22dab	Diversion from Leap Creek below USGS gage	dry	—	—	Tc
LP 4.0	(C-39-13)23cbc	Leap Creek above Tc-Ti contact	.72	370	11.5	Tc/Ti
LP 5.0	(C-39-13)23ccd	Leap Creek below Ti-Tc contact	.71	375	11.5	Ti/Tc
LP 6.0	(C-39-13)26bda	Leap Creek at Tc-Ti contact near Peters Leap	.59	360	16.0	Tc/Ti
LP 7.0	(C-39-13)25cdb	Leap Creek 0.5 mi above I-15 at tributary inflow from north	.54	360	11.5	Qb
LP 8.0	(C-39-13)36acc	Leap Creek 75 ft above confluence with Ash Creek	.46	355	15.0	Qb/Qu
		Third seepage investigation, October 29, 1998				
LP 1.0	(C-39-13)22cbc	Leap Creek below small tributary inflow below Coal Hollow	1.24	355	8.0	Jc/Jn
LP 2.0	(C-39-13)22caa	Leap Creek at first trail crossing at midpoint of Jn outcrop	1.10	355	8.0	Jn
LP 2.8	(C-39-13)22dab	Maple Hollow inflow above USGS gage	.06	590	—	Tc
LP 3.0	(C-39-13)22dab	Leap Creek at USGS gage (09406640)	1.18	365	7.5	Tc; GH = 3.66 ft at 1000 hours
LP 3.3	(C-39-13)22dab	Diversion from Leap Creek below USGS gage	dry	—	—	Tc
LP 4.0	(C-39-13)23cbc	Leap Creek above Tc-Ti contact	—	—	—	Tc/Ti; no measurement
LP 5.0	(C-39-13)23ccd	Leap Creek below Ti-Tc contact	1.30	—	9.5	Ti/Tc
LP 6.0	(C-39-13)26bda	Leap Creek at Tc-Ti contact near Peters Leap	1.06	370	9.5	Tc/Ti
LP 7.0	(C-39-13)25cdb	Leap Creek 0.5 mi above I-15 at tributary inflow from north	.97	370	8.5	Qb
LP 8.0	(C-39-13)36acc	Leap Creek 75 ft above confluence with Ash Creek	.90	365	10.0	Qb/Qu



Base from U.S. Geological Survey
digital data, 1:100,000, 1982
Universal Transverse Mercator projection
Zone 12

0 5,000 10,000 FEET
0 1,000 2,000 METERS

CONTOUR INTERVAL 1,000 FEET

EXPLANATION

- - - - - - **Approximate geologic contact**–Formations defined in figure 1.

LP 2.0 ● **Streamflow-measurement site**

Figure 3. Location of Leap Creek seepage investigation and streamflow-measurements site, Washington County, Utah, 1998.

and LP 3.0 ranged from 0.11 ft^3/s on October 13, 1998, to 1.20 ft^3/s on May 29, of which 0.59 ft^3/s was inflow from Maple Hollow. Losses computed on October 29 (0.12 ft^3/s) closely approximated the losses computed on October 13. Only the normalized differences for the May 29 investigation between LP 1.0 and LP 3.0 exceeded the normalized error (table 2).

Site LP 2.0 was located near the downstream contact of the Navajo Sandstone outcrop and was added after the first seepage investigation to better define the loss-gain relation for this channel reach. The 2,890-ft reach between LP 1.0 and LP 2.0 lost 0.02 and 0.14 ft^3/s on October 13 and 29, respectively, but neither loss exceeded the normalized error (fig. 4, table 2).

The 2,030-ft reach between LP 2.0 and LP 3.0 lost 0.09 ft^3/s on October 13 and gained 0.02 ft^3/s on October 29. Neither loss nor gain exceeded the normalized error (fig. 4, table 2).

The 1,560-ft reach between LP 3.0 and LP 4.0 had a computed loss of 0.06 ft^3/s on May 29 and a computed gain of 0.04 ft^3/s on October 13. Neither the loss nor gain exceeded the normalized error (table 2).

Sites LP 4.0 and LP 5.0 are immediately upstream and downstream of a 1,160-ft long outcrop of the Pine Valley laccolith that intrudes into the Claron Formation. The intrusion was impermeable in this reach as indicated by nearly unchanged streamflow measurements upstream and downstream of the outcrop on May 29 and October 13 (fig. 4, tables 1 and 2). Streamflow at LP 4.0 was not measured on October 29.

The 2,720-ft reach between LP 3.0 and LP 5.0 had a computed loss of 0.02 ft^3/s on May 29, and computed gains of 0.03 ft^3/s on October 13, 1998, and 0.12 ft^3/s on October 29, respectively. Neither the loss nor the gains exceeded the normalized error (table 2).

The 3,220-ft reach between LP 5.0 and LP 6.0 had a computed gain of 1.12 ft^3/s during the higher streamflows of May 29, but at flows more typical of base flow, losses were 0.12 ft^3/s on October 13 and 0.24 ft^3/s on October 29. The gain and the two losses exceeded the normalized error (fig. 4, table 2). Site LP 6.0 (near upper Peters Leap) was located where the east-dipping Claron Formation is truncated by a Pine Valley intrusion on the south side of the creek and unconsolidated fluvial deposits capped by Quaternary basalt flows on the north side of the creek.

Quaternary basalt flows crop out in the 5,970-ft reach between LP 6.0 and LP 7.0, which was at the confluence of Leap Creek and a major tributary channel from the north. This reach gained 0.21 ft^3/s at higher streamflows (May 29) but lost 0.05 ft^3/s and 0.09 ft^3/s on October 13 and 29, respectively, when streamflow was near base flow. Neither the gain nor the losses exceeded the normalized error (table 2).

The 3,550-ft reach on Leap Creek between LP 7.0 and LP 8.0 also traverses Quaternary-aged basalt. This reach lost water during all three seepage investigations. The greatest loss (1.54 ft^3/s) occurred during higher flow conditions on May 29. Computed losses during base flow on October 13 and 29 between LP 7.0 and LP 8.0 are 0.08 ft^3/s and 0.07 ft^3/s, respectively. Only losses on May 29 and October 13 exceeded or equaled the normalized error (fig. 4, table 2). The contact of the basalt and the Quaternary unconsolidated alluvial deposits is at the confluence of Leap Creek and Ash Creek (Hurlow, 1998, pl. 1) at LP 8.0.

South Ash Creek

Four seepage investigations were completed on South Ash Creek on May 12, August 20, October 1, and October 30, 1998 (table 3). The additional investigation on August 20 occurred when the effects of evapotranspiration were potentially more prevalent than during the other three investigations and, apparently, when upper Pintura diversion was being activated and put into operation. These two factors add complexity to the data interpretation.

A gage on South Ash Creek (09406700; discontinued at end of water year 1982) was temporarily reactivated from April 24, 1998, through the end of the investigation in October 1998 to collect gage-height data for this investigation (fig. 5). The period of record for the gage is water years 1967-82. Comparison of the monthly mean discharge (which is the arithmetic mean of the daily mean discharge for a specific month) for 1967-82 indicates that the fourth highest monthly mean discharge (36.1 ft^3/s) occurred in May 1998; the third highest (7.31 ft^3/s) occurred in August 1998, and the highest (4.25 ft^3/s) occurred in October 1998 and 1973. Wetter-than-normal conditions prevailed when these seepage data were collected.

Streamflow was measured at 10 main channel sites, 3 sites at diversions, and 1 site at an inflow (return flow from upper Pintura diversion at S 5.2), along the 27,690-ft reach of South Ash Creek (fig. 5). The reach extends from the confluence of Mill and Harmon Creeks to the confluence of South Ash Creek with Ash Creek. A 5,300-ft reach on Harmon Creek and a

Table 2. Error analysis for specified reaches on Leap Creek, Washington County, Utah

[—, no data available; Individual reach, specifies the interval between consecutive upstream and downstream streamflow-measurement sites; Composite reach, specifies the interval between specified streamflow-measurement sites, which are combined to assess the loss or gain of a specific hydrogeologic unit]

Site ID: Informal site designation. The first number specifies the upstream streamflow-measurement site and the second number the downstream streamflow-measurement site. Interval between specified sites is the reach. See table 1 for additional information.

Hydrogeologic unit: Description of rock formation that outcrops at each streamflow-measurement site in specified reach: Qb, Quaternary basalt flows; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; Ti, Tertiary Pine Valley laccolithic intrusive rocks; Tc, Tertiary Claron Formation; Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone.

Distance: ft, feet (length of reach between streamflow-measurement sites); TOTAL is distance, in feet, of all reaches of seepage investigation.

Streamflow: Q_{us}, streamflow at upstream measurement site in reach; Q_{ds}, streamflow at downstream site; Inflow from tributaries designated with (+) sign; Diversions designated with (-) sign; ft^3/s, cubic feet per second; No Meas, streamflow was not measured at site.

Accuracy of streamflow measurement: A qualitative evaluation of several factors, such as cross-section uniformity, velocity uniformity, and stream bed conditions, that could, in the opinion of the streamgager, affect the accuracy of the measurement: G, good, measured streamflow is within 5 percent of "true" streamflow; F, fair, within 8 percent; P, poor, measured streamflow is more than 8 percent of the "true" streamflow.

Normalized percent difference: $N_d\%$, see Equation 2 for definition.

Normalized percent error: $N_e\%$, see Equation 3 for definition.

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of streamflow measure-ment	Downstream streamflow (Q_{ds}) (ft^3/s)	Accuracy of streamflow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of streamflow measure-ment	Normalized percent difference ($N_d\%$)	Normalized percent error ($N_e\%$)
First seepage investigation, May 29, 1998										
Individual reach										
LP 1.0	Jc/Jn	0	No Meas	—	6.63	F	0	—	—	—
LP 1.0-2.0	Jn	2,890	6.63	F	No Meas	—	+.59	P	—	—
LP 2.0-3.0	Jn/Tc	2,030	No Meas	—	6.02	G	0	—	—	—
LP 3.0-4.0	Tc	1,560	6.02	G	5.96	G	0	—	-1.00	-9.95
LP 4.0-5.0	Ti	1,160	5.96	G	6.00	G	0	—	.67	9.97
LP 5.0-6.0	Tc	3,220	6.00	G	7.12	G	0	—	15.73	9.21
LP 6.0-7.0	Qb	5,970	7.12	G	7.33	F	0	—	2.86	12.86
LP 7.0-8.0	Qb	3,550	7.33	F	5.79	F	0	—	-21.01	-14.32
	TOTAL	20,380								
Composite reach										
LP 1.0-3.0	Jn/Tc	4,920	6.63	F	6.02	G	+.59	P	-16.62	-12.17
LP 3.0-5.0	Tc/Ti/Tc	2,720	6.02	G	6.00	G	0	—	-.33	-9.98
LP 3.0-6.0	Tc/Ti/Tc	8,660	6.02	G	7.12	G	0	—	15.45	9.23
LP 6.0-8.0	Qb	10,860	7.12	G	5.79	F	0	—	-18.68	-11.51
Second seepage investigation, October 13, 1998										
Individual reach										
LP 1.0	Jc/Jn	0	No Meas	-	.79	F	0	—	—	—
LP 1.0-2.0	Jn	2,890	.79	F	.77	F	0	—	-2.53	-15.80
LP 2.0-3.0	Jn/Tc	2,030	.77	F	.68	P	0	—	-11.69	-15.06
LP 3.0-4.0	Tc	1,560	.68	P	.72	P	0	—	5.56	15.56
LP 4.0-5.0	Ti	1,160	.72	P	.71	P	0	—	-1.39	-15.89
LP 5.0-6.0	Tc	3,220	.71	P	.59	F	0	—	-16.90	-14.65
LP 6.0-7.0	Qb	5,970	.59	F	.54	P	0	—	-8.47	-15.32
LP 7.0-8.0	Qb	3,550	.54	P	.46	P	0	—	-14.81	-14.81
	TOTAL	20,380								

Table 2. Error analysis for specified reaches on Leap Creek, Washington County, Utah—Continued

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft³/s)	Accuracy of streamflow measure-ment	Downstream streamflow (Q_{ds}) (ft³/s)	Accuracy of streamflow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft³/s)	Accuracy of streamflow measure-ment	Normalized percent difference (N_d%)	Normalized percent error (N_e%)
Second seepage investigation, October 13, 1998—Continued										
Composite reach										
LP 1.0-3.0	Jn	4,920	.79	F	.68	P	0	—	-13.92	-14.89
LP 3.0-5.0	Tc/Ti/Tc	2,720	.68	P	.71	P	0	—	4.43	15.66
LP 3.0-6.0	Tc/Ti/Tc	8,660	.68	P	.59	F	0	—	-13.24	-14.94
LP 6.0-8.0	Qb	10,860	.59	F	.46	P	0	—	-22.03	-14.24
Third seepage investigation, October 29, 1998										
Individual reach										
LP 1.0	Jc/Jn	0	No Meas	—	1.24	F	0	—	—	—
LP 1.0-2.0	Jn	2,890	1.24	F	1.10	F	0	—	-11.29	-15.10
LP 2.0-3.0	Jn/Tc	2,030	1.10	F	1.18	F	+.06	P	1.69	15.86
LP 3.0-4.0	Tc	1,560	1.18	F	No Meas	—	0	—	—	—
LP 4.0-5.0	Ti	1,160	No Meas	—	1.30	F	0	—	—	—
LP 5.0-6.0	Tc	3,220	1.30	F	1.06	F	0	—	-18.46	-14.52
LP 6.0-7.0	Qb	5,970	1.06	F	.97	P	0	—	-8.49	-15.32
LP 7.0-8.0	Qb	3,550	.97	P	.90	P	0	—	-7.22	-15.42
	TOTAL	20,380								
Composite reach										
LP 1.0-3.0	Jn	4,920	1.24	F	1.18	F	+.06	P	-9.23	-15.26
LP 3.0-5.0	Tc/Ti/Tc	2,720	1.18	F	1.30	F	0	—	9.23	15.26
LP 3.0-6.0	Tc/Ti/Tc	8,660	1.18	F	1.06	F	0	—	-10.17	-15.19
LP 6.0-8.0	Qb	10,860	1.06	F	.90	P	0	—	-15.09	-14.79

3,700-ft reach on Mill Creek immediately upstream of their confluence with South Ash Creek were measured during the May 12, August 20, and October 1, 1998, seepage investigations. Both tributary channels flow on undifferentiated Cretaceous rocks. South Ash Creek flows on the west-dipping Carmel Formation for about one-quarter mi below the confluence of Harmon and Mill Creeks (S 1.0) before entering a deep canyon incised into the Navajo Sandstone, which outcrops for about 3 mi downstream to near the main channel site at S 5.0. Between S 4.0 and S 5.0, it is assumed that the unconsolidated alluvial deposits thinly cover the Navajo Sandstone, which is exposed at the edge of the floodplain in the nearby hillsides. East-dipping rocks of the Claron Formation are exposed between S 5.0 and S 7.0. South Ash Creek downstream of lower Pintura diversion (S 7.0) flows on Quaternary unconsolidated deposits.

Streamflow was measured at two sites on both Harmon (S 0.2, S 0.8) and Mill (S 0.4, S 0.6) Creeks during three seepage investigations (table 3). Gains of 0.7 ft³/s and 0.5 ft³/s were computed on May 12 between upstream and downstream sites for Harmon and Mill Creeks when streamflows were considerably greater than base flow and soils were wet from recent snowmelt runoff. Losses of 0.07 ft³/s and 0.03 ft³/s were computed on August 20. On October 1, Mill Creek gained 0.32 ft³/s while Harmon Creek lost 0.08 ft³/s. Normalized differences for the May, August, and October investigations were less than the normalized error (table 4) and, therefore, none of the losses or gains in this reach are considered significant.

Measured streamflow at S 0.6 and S 0.8 are combined, then compared with measured streamflow at S 1.0 to determine losses or gains for this short reach that flows across a thin outcrop of Carmel Formation. Losses were computed for May 12, August 20, and October 30 and a gain was computed for October 1. Only the August loss was greater than the normalized error (fig. 6, table 4).

The 4,920-ft long reach between S 1.0 and S 2.0 bisects a prominent north-northeast trending zone of high-density fractures and joints. During the May 12 investigation, this reach gained 3.0 ft³/s. The gain was supported by check measurements on May 14 (table 3). Though the computed gain was relatively large, it was

Table 3. Measurements of streamflow, specific conductance, and temperature of water from South Ash Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah

[—, no data available; Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone; Ks, undifferentiated Cretaceous rocks; Qb, Quaternary basalt flows; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; Ti, Tertiary Pine Valley laccolithic intrusive rocks; Tc, Tertiary Claron Formation; ft, feet; mi, mile]

Site ID: Informal site designation: S 1.0, whole number designation indicates the streamflow-measurement site on South Ash Creek main channel, ascending in downstream order; S 1.2, even decimal number indicates tributary inflow that enters South Ash Creek between main channel measurement site at S 1.0 and S 2.0; S 6.5, odd decimal number indicates outflow (diversion) between main channel measurement sites at S 6.0 and S 7.0.

Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.

Description of site: General description of streamflow-measurement site. USGS, United States Geological Survey; USFS, United States Forest Service; 09406700, number of discontinued streamflow-gaging station operated by the USGS.

Streamflow: ft^3/s, cubic feet per second; dry, no flow.

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

Temperature: °C, degrees Celsius.

Remarks: Date is month, day, and year that previous data were collected. GH is gage height of USGS gage at indicated military time. Q, measurement of streamflow.

Site ID	Location	Description of site	Stream-flow (ft^3/s)	Specific conduct-ance (μS/cm)	Temper-ature (°C)	Remarks
		Previous measurements				
—	(C-39-13)29dcc	South Ash Creek at Jc/Jn contact	3.58	165	7.0	10-09-95
—	(C-40-13) 3abc	South Ash Creek at Jn/Qu contact	2.20	160	9.0	10-09-95
		First seepage investigation, May 12, 1998				
S 0.2	(C-39-13)30dcd	Harmon Creek about 1 mi above confluence with Mill Creek	12.6	200	6.5	Ks
S 0.4	(C-39-13)29cbb	Mill Creek 0.7 mi above confluence with Harmon Creek	20.1	160	7.5	Ks
S 0.6	(C-39-13)29cda	Mill Creek 600 ft above confluence with Harmon Creek	20.6	160	8.0	Ks/Jc
S 0.8	(C-39-13)29dcc	Harmon Creek 150 ft above confluence with Mill Creek	13.3	205	8.5	Ks/Jc
S 1.0	(C-39-13)29dcc	South Ash Creek at USGS gage (09406700)	33.4	190	6.5	Jc/Jn; GH=2.22 ft at 1010 hours
			33.8	180	9.0	Jc/Jn; GH=2.21 ft at 1455 hours
			—	—	—	Jc/Jn; GH=2.20 ft at 1615 hours
S 1.2	(C-39-13)29dca	Tributary inflow from north below gage	dry	—	—	Observed on 5-14; dry for days
S 2.0	(C-39-13)32daa	South Ash Creek near USFS gate	36.6	180	7.5	Jn; see 5-14-98
S 3.0	(C-39-13)33cdc	South Ash Creek near 1951 drill hole site	32.5	180	8.5	Jn
S 3.5	(C-40-13) 4aab	Upper Pintura diversion from South Ash Creek	dry	—	—	Jn/Qu; diversion inactive
S 4.0	(C-40-13) 4aab	South Ash Creek below upper Pintura diversion	31.3	180	9.0	Jn/Qu
S 5.0	(C-40-13) 3baa	South Ash Creek 0.5 mi above lower Pintura diversion	30.2	180	—	Jn/Tc
			30.5	180	8.5	Jn/Tc
S 5.2	(C-39-13) 3baa	Upper Pintura diversion 75 ft above confluence with South Ash Creek	dry	—	—	Tc/Qu; diversion inactive
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	—	—	—	Tc; no measurement
S 6.5	(C-40-13) 3abc	Lower Pintura diversion from South Ash Creek	15.9	180	8.5	Tc
S 7.0	(C-40-13) 3abc	South Ash Creek 150 ft below lower Pintura diversion	20.5	180	8.5	Tc/Qu
S 8.0	(C-40-13) 3daa	South Ash Creek near lava constriction	26.9	180	—	Qu/Qb
S 9.0	(C-40-13)11abb	South Ash Creek below I-15 bridge, above old U.S. 91	24.6	180	—	Qu
S 10.0	(C-40-13)11ada	South Ash Creek above confluence with Ash Creek	25.7	180	—	Qu
		Measurement checks at specified sites on May 14, 1998, to corroborate first seepage investigation on May 12, 1998				
S 1.0	(C-39-13)29dcc	South Ash Creek at discontinued USGS gage (09406700)	32.1	—	7.5	Jc/Jn; GH=2.16 ft at1200 hours
S 1.2	(C-39-13)29dca	Tributary inflow from north below gage	dry	—	—	Channel dry for many days
S 2.0	(C-39-13)32daa	South Ash Creek near U.S. Forest Service gate	34.4	—	8.0	Jn; corroborates 5-12 gains
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	29.1	—	9.5	Tc
S 6.5	(C-40-13) 3abc	Lower Pintura diversion from South Ash Creek	13.6	—	9.5	Tc; corroborates 5-12 measurement

Table 3. Measurements of streamflow, specific conductance, and temperature of water from South Ash Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah—Continued

Site ID	Location	Description of site	Streamflow (ft^3/s)	Specific conductance ($\mu S/cm$)	Temperature (°C)	Remarks
		Second seepage investigation, August 20, 1998				
S 0.2	(C-39-13)30dcd	Harmon Creek about 1 mi above confluence with Mill Creek	2.79	185	10.5	Ks
S 0.4	(C-39-13)29cbb	Mill Creek 0.7 mi above confluence with Harmon Creek	5.48	170	10.0	Ks
S 0.6	(C-39-13)29cda	Mill Creek 600 ft above confluence with Harmon Creek	5.45	165	11.0	Ks/Jc
S 0.8	(C-39-13)29dcc	Harmon Creek 150 ft above confluence with Mill Creek	2.72	190	13.0	Ks/Jc
S 1.0	(C-39-13)29dcc	South Ash Creek at USGS gage (09406700)	7.29	180	—	Jc/Jn; Q at 0930 hours
			6.90	180	—	Jc/Jn; GH=1.56 ft at 1400 hours
S 1.2	(C-39-13)29dca	Tributary inflow from north below gage	—	—	—	Assumed to be dry
S 2.0	(C-39-13)32daa	South Ash Creek near USFS gate	7.06	180	11.0	Jn
S 3.0	(C-39-13)33cdc	South Ash Creek near 1951 drill hole site	6.58	180	14.5	Jn
S 3.5	(C-40-13) 4aab	Upper Pintura diversion	2.01	180	17.5	Jn/Qu; activated by 1515 hrs
S 4.0	(C-40-13) 4aab	South Ash Creek below upper Pintura diversion	4.72	180	17.5	Jn/Qu
S 5.0	(C-40-13) 3baa	South Ash Creek 0.5 mi above lower Pintura diversion	3.74	180	14.0	Jn/Tc
S 5.2	(C-39-13) 3baa	Upper Pintura diversion 75 ft above confluence with South Ash Creek	dry	—	—	Tc/Qu; 0940 hours
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	5.84	180	16.0	Tc; Q measured at 1035 hours
			5.36	180	28.5	Tc; Q measured at 1655 hours
S 6.5	(C-40-13) 3abc	Lower Pintura diversion from South Ash Creek	5.85	180	14.5	Tc
S 7.0	(C-40-13) 3abc	South Ash Creek 150 ft below lower Pintura diversion	.19	—	16.5	Tc/Qu
S 8.0	(C-40-13) 3daa	South Ash Creek near lava constriction	3.26	180	15.5	Qu/Qb; Gain from leaky diversion
S 9.0	(C-40-13)11abb	South Ash Creek below I-15 bridge, above old U.S. 91	1.99	180	21.5	Qu
S 10.0	(C-40-13)11ada	South Ash Creek above confluence with Ash Creek	1.55	180	24.0	Qu
		Measurement checks at specified sites on August 21, 1998, to corroborate second seepage investigation on August 20, 1998				
S 5.2	(C-39-13) 3baa	Upper Pintura diversion 75 ft above confluence with South Ash Creek	2.04	—	15.0	Tc/Qu; dry on 8-20-98
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	5.38	180	—	Tc
S 7.0	(C-40-13) 3abc	South Ash Creek 150 ft below lower Pintura diversion	0.03	—	—	Tc/Qu
		Third seepage investigation, October 1, 1998				
S 0.2	(C-39-13)30dcd	Harmon Creek about 1 mi above confluence with Mill Creek	1.73	215	7.0	Ks
S 0.4	(C-39-13)29cbb	Mill Creek 0.7 mi above confluence with Harmon Creek	2.96	180	—	Ks
S 0.6	(C-39-13)29cda	Mill Creek 600 ft above confluence with Harmon Creek	3.28	175	8.5	Ks/Jc
S 0.8	(C-39-13)29dcc	Harmon Creek 150 ft above confluence with Mill Creek	1.65	200	9.0	Ks/Jc
S 1.0	(C-39-13)29dcc	South Ash Creek at USGS gage (09406700)	4.91	205	7.5	Jc/Jn; Q measured at 0920 hours
			5.09	200	9.5	Jc/Jn; GH=1.46 at 1330 hours
S 1.2	(C-39-13)29dca	Tributary inflow from north below gage	—	—	—	Assumed to be dry
S 2.0	(C-39-13)32daa	South Ash Creek near USFS gate	4.87	200	6.5	Jn
S 3.0	(C-39-13)33cdc	South Ash Creek near 1951 drill hole site	5.10	195	9.0	Jn
S 3.5	(C-40-13) 4aab	Upper Pintura diversion	.56	—	11.0	Jn/Qu; measured upstream of grate
S 4.0	(C-40-13) 4aab	South Ash Creek below upper Pintura diversion	4.08	195	11.5	Jn/Qu
S 5.0	(C-40-13) 3baa	South Ash Creek 0.5 mi above lower Pintura diversion	3.08	210	9.0	Jn/Tc
S 5.2	(C-39-13) 3baa	Upper Pintura diversion 75 ft above confluence with South Ash Creek	.34	210	10.0	Tc/Qu
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	3.44	205	10.5	Tc; Q measured at 1055 hours
			3.61	195	13.5	Tc; Q measured at 1640 hours
S 6.5	(C-40-13) 3abc	Lower Pintura diversion from South Ash Creek	3.19	200	11.5	Tc
S 7.0	(C-40-13) 3abc	South Ash Creek 150 ft below lower Pintura diversion	.02	200	12.0	Tc/Qu
S 8.0	(C-40-13) 3daa	South Ash Creek near lava constriction	1.68	210	14.0	Qu/Qb; Gain from leaky diversion?
S 9.0	(C-40-13)11abb	South Ash Creek below I-15 bridge, above old US 91	.69	205	14.0	Qu
S 10.0	(C-40-13)11ada	South Ash Creek above confluence with Ash Creek	.50	205	17.0	Qu

Table 3. Measurements of streamflow, specific conductance, and temperature of water from South Ash Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah—Continued

Site ID	Location	Description of site	Stream-flow (ft^3/s)	Specific conduct-ance ($\mu S/cm$)	Temper-ature (°C)	Remarks
		Fourth seepage investigation, October 30, 1998				
S 0.2	(C-39-13)30dcd	Harmon Creek about 1 mi above confluence with Mill Creek	—	—	—	Ks, did not measure
S 0.4	(C-39-13)29cbb	Mill Creek 0.7 mi above confluence with Harmon Creek	—	—	—	Ks, did not measure
S 0.6	(C-39-13)29cda	Mill Creek 600 ft above confluence with Harmon Creek	3.14	195	6.5	Ks/Jc; measured 30 ft above culvert
S 0.8	(C-39-13)29dcc	Harmon Creek 150 ft above confluence with Mill Creek	2.09	220	6.0	Ks/Jc, measured 20 ft above bridge
S 1.0	(C-39-13)29dcc	South Ash Creek at USGS gage (09406700)	4.65	210	6.5	Jc/Jn; Q measured at 0950 hours
			4.87	210	8.0	Jc/Jn; GH=1.46 at 1400 hours
S 1.2	(C-39-13)29dca	Tributary inflow from north below gage	dry	—	—	Observed to be dry
S 2.0	(C-39-13)32daa	South Ash Creek near USFS gate	4.57	210	6.5	Jn
S 3.0	(C-39-13)33cdc	South Ash Creek near 1951 drill hole site	6.09	210	7.5	Jn
S 3.5	(C-40-13) 4aab	Upper Pintura diversion	.11	210	7.0	Jn/Qu; measured upstream of grate
S 4.0	(C-40-13) 4aab	South Ash Creek below upper Pintura diversion	3.76	210	7.0	Jn/Qu
S 5.0	(C-40-13) 3baa	South Ash Creek 0.5 mi above lower Pintura diversion	3.52	210	7.5	Jn/Tc
S 5.2	(C-39-13) 3baa	Upper Pintura diversion 75 ft above confluence with South Ash Creek	dry	—	—	Tc/Qu; no flow
S 6.0	(C-40-13) 3abc	South Ash Creek 200 ft above lower Pintura diversion	4.01	210	8.0	Tc; Q measured at 1010 hrs
			3.01	—	8.5	Tc; Q measured at 1145 hrs
S 6.5	(C-40-13) 3abc	Lower Pintura diversion from South Ash Creek	3.56	210	8.5	Tc; 100 ft below diversion
S 7.0	(C-40-13) 3abc	South Ash Creek 150 ft below lower Pintura diversion	.02	210	9.0	Tc/Qu; measured at 1100 hrs
			.02	—	11.5	Tc/Qu; measured at 1500 hrs
S 8.0	(C-40-13) 3daa	South Ash Creek near lava constriction	1.77	210	10.5	Qu/Qb; Gain from leaky diversion
S 9.0	(C-40-13)11abb	South Ash Creek below I-15 bridge, above old U.S. 91	1.30	205	10.5	Qu
S 10.0	(C-40-13)11ada	South Ash Creek above confluence with Ash Creek	1.00	210	12.5	Qu

less than the normalized error (fig. 6, table 4). Measurements at lower streamflows on August 20, October 1, and October 30 had losses in this reach that were also less than the normalized error (fig. 6, table 4). The potential importance of this fracture zone to act as a conduit for significant losses and gains was not supported by the data.

The 4,680-ft reach between S 2.0 and S 3.0 lost 4.1 ft^3/s and 0.48 ft^3/s on May 12 and August 20, respectively, and gained 0.23 ft^3/s on October 1 and 1.52 ft^3/s on October 30. Only the October 30 gain was greater than the normalized error (fig. 6, table 4). Reasons for the October 30 gain between S 2.0 and S 3.0 are not known, but a loss of similar magnitude occurred on the same date downstream at sites S 4.0 and S 6.0. A pulse of water of unknown origin that was not recorded at the temporary gage at S 1.0 seems to have traversed the reach between S 2.0 and S 6.0 on October 30.

The Navajo Sandstone reach between S 3.0 and S 4.0 lost 1.2 ft^3/s on May 12, gained 0.15 ft^3/s on August 20, lost 0.46 ft^3/s on October 1, and on October 30 lost 2.22 ft^3/s, which was approximately the amount gained between S 2.0 and S 3.0 on the same date. Only the computed loss on October 30 exceeded the normalized error (fig. 6, table 4). There were no retention structures, known or observed sources of inflow, or other identifiable features or conditions that explain the gain between S 2.0 and S 3.0 and the loss of similar magnitude between S 3.0 and 4.0 during the October 30 seepage investigation.

The 4,190-ft reach between S 4.0 and S 5.0 consistently lost water during all four seepage investigations. The losses appear to be independent of the stream stage and the status of the upper Pintura diversion at S 3.5. The amount of water lost ranged from a maximum of 1.1 ft^3/s on May 12 at higher streamflows to a minimum of 0.24 ft^3/s on October 30 when flows approximated base flow. Losses computed for August 20 (0.98 ft^3/s) and October 1 (1.00 ft^3/s) exceeded the normalized error and approximate computed losses for May 12 when flows in South Ash Creek were about five times higher.

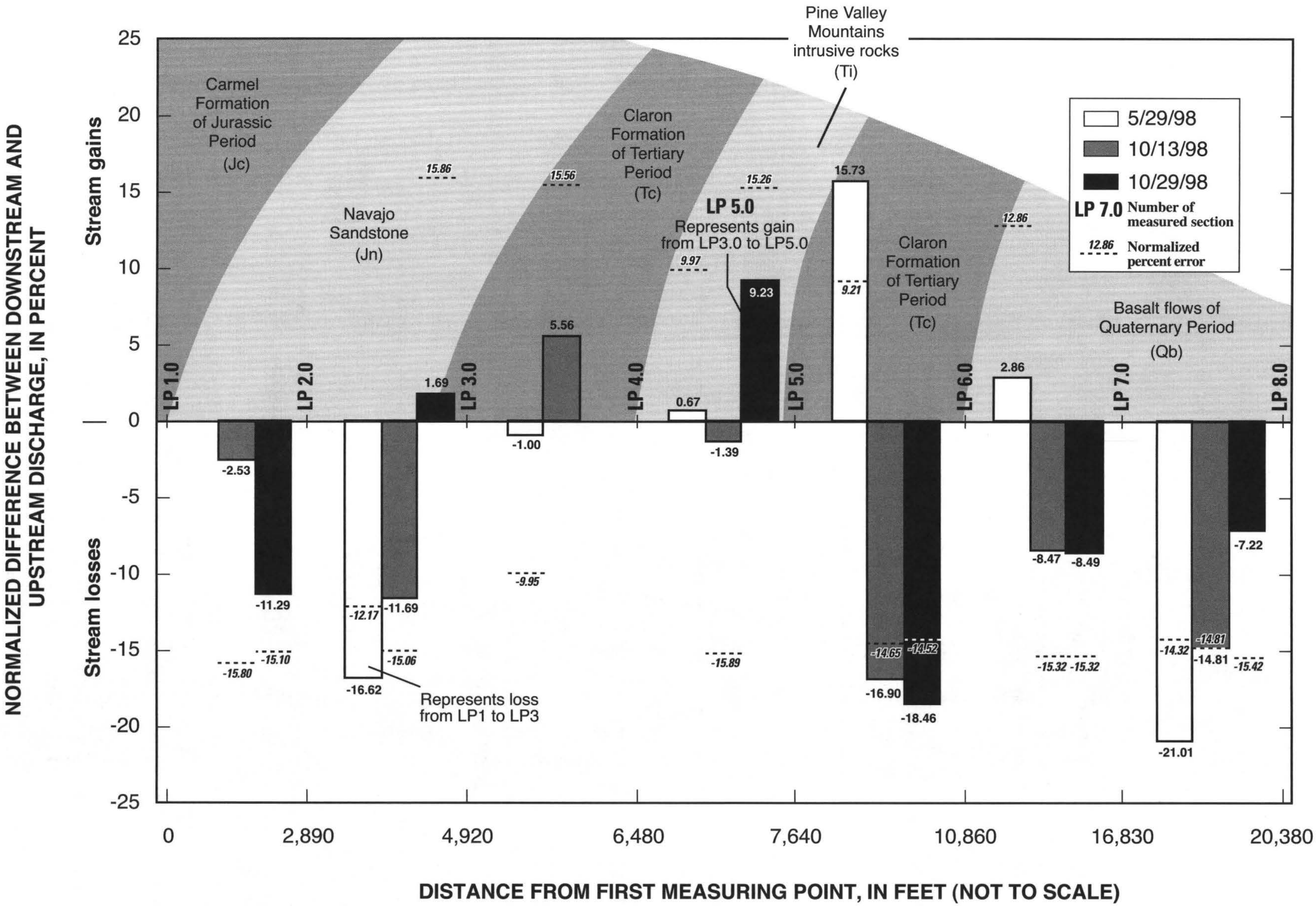
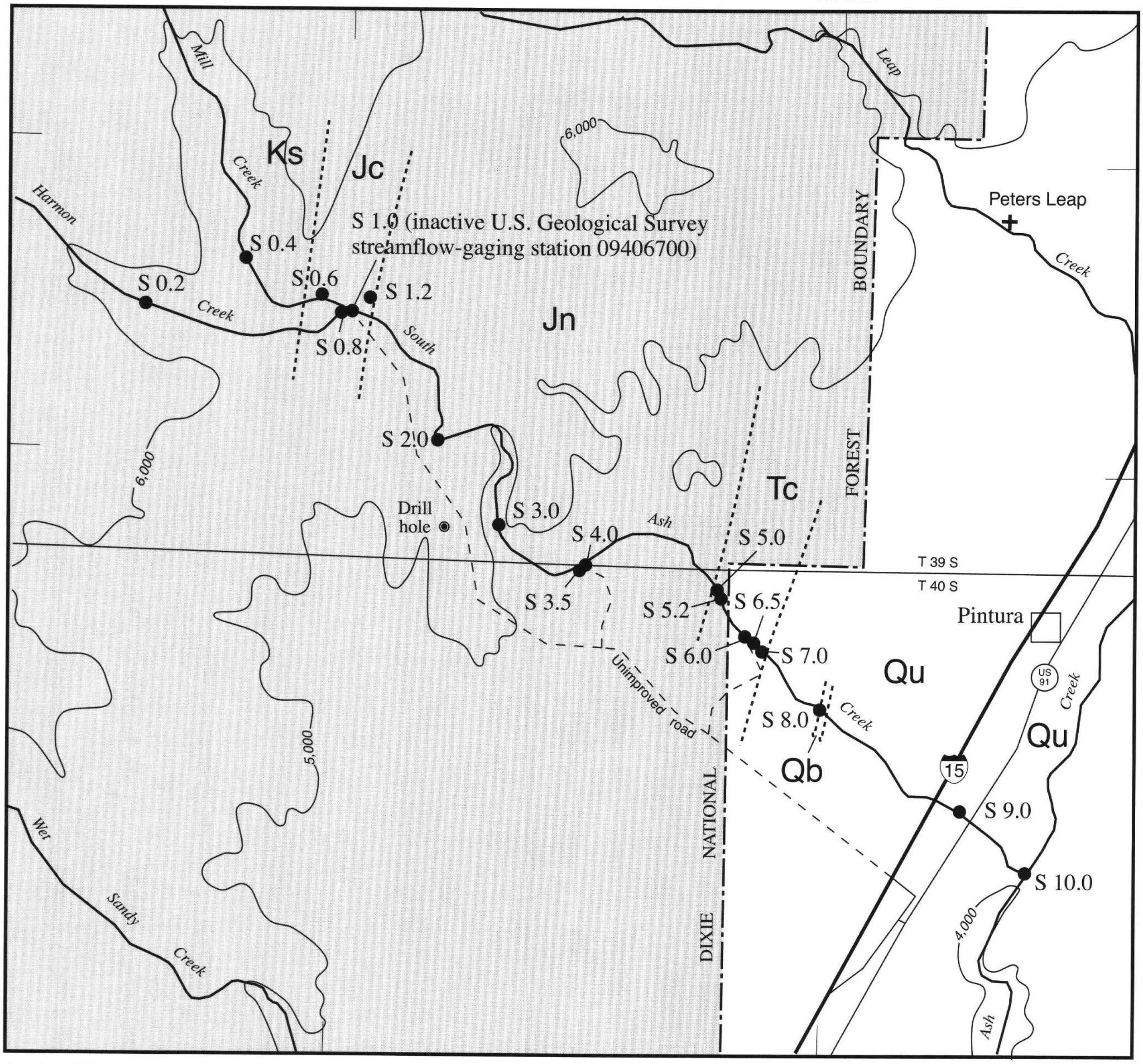
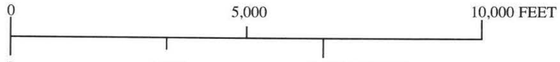


Figure 4. Gaining and losing reaches of Leap Creek during three seepage investigations in Washington County, Utah, 1998.



Base from U.S. Geological Survey
digital data, 1:100,000, 1982
Universal Transverse Mercator projection
Zone 12



CONTOUR INTERVAL 1,000 FEET

EXPLANATION

- - - - - - - - - - **Approximate geologic contact**–Formations defined in figure 1.

S 2.0 ● **Streamflow-measurement site**

Figure 5. Location of South Ash Creek seepage investigation and streamflow-measurement sites, Washington County, Utah, 1998.

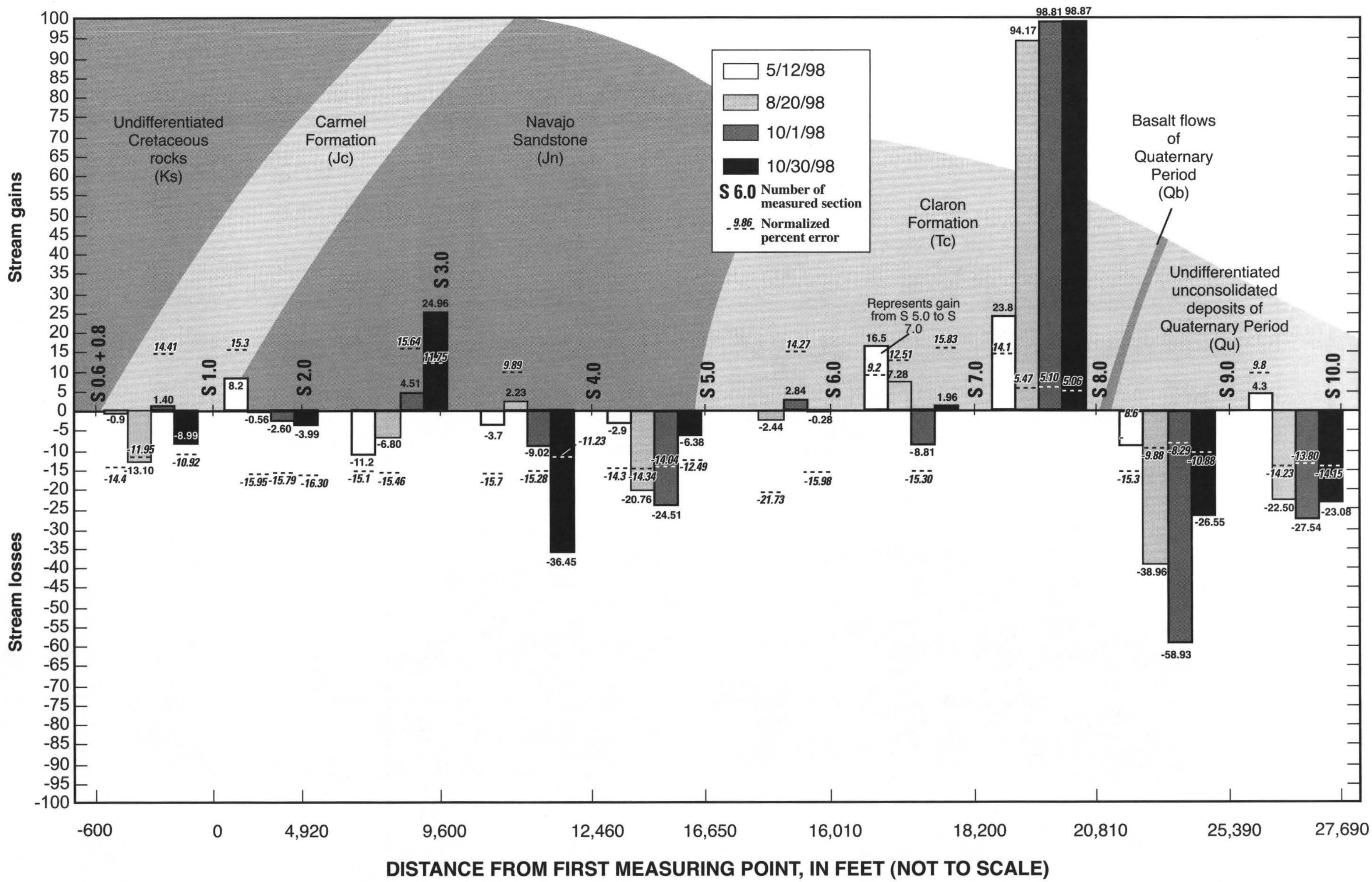


Figure 6. Gaining and losing reaches of South Ash Creek during four seepage investigations in Washington County, Utah, 1998.

Table 4. Error analysis for specified reaches on South Ash Creek, Washington County, Utah

[—, no data available; Individual reach, specifies the interval between consecutive upstream and downstream streamflow-measurement sites; Composite reach, specifies the interval between specified streamflow-measurement sites, which are combined to assess the loss or gain of a specific hydrogeologic unit]

Site ID: Informal site designation. The first number specifies the upstream streamflow-measurement site and the second number the downstream streamflow-measurement site. Interval between specified sites is the reach. See table 3 for additional information.

Hydrogeologic unit: Description of rock formation that outcrops at each streamflow-measurement site in specified reach: Qb, Quaternary basalt flows; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; Ti, Tertiary Pine Valley laccolithic intrusive rocks; Tc, Tertiary Claron Formation; Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone.

Distance: ft, feet. Distance of reach between streamflow-measurement sites; (-) indicates distance upstream from site at S 1.0; {1,550}, distance not used to determine total. TOTAL is distance, in feet, sum of all reaches between streamflow-measurement sites.

Streamflow: Q_{us}, streamflow at upstream measurement site in reach; Q_{ds}, streamflow at downstream site. Inflow from tributaries or return flow of diversion designated with (+) sign and is the sum of all inflows between specified sites; Diversions designated with (-) sign; ft^3/s, cubic feet per second; No Meas, streamflow was not measured at site.

Accuracy of streamflow measurement: A qualitative evaluation of several factors, such as cross-section and velocity uniformity, and stream bed conditions, that could, in the opinion of the streamgager, affect the accuracy of the measurement: G, good, measured streamflow is within 5 percent of "true" streamflow; F, fair, within 8 percent; P, poor, measured streamflow is more than 8 percent of the "true" streamflow; e, estimated streamflow probably within 25 percent of "true" streamflow based on measurement made on following day. For a site with two measurements and two accuracy ratings, the average of the two ratings is used. For example, if two measurements were rated F and G, the average accuracy would be 6.5%.

Normalized percent difference: $N_d\%$, see Equation 2 for definition.

Normalized percent error: $N_e\%$, see Equation 3 for definition.

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of streamflow measure-ment	Down-stream streamflow (Q_{ds}) (ft^3/s)	Accuracy of stream-flow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of streamflow measure-ment	Normalized percent difference ($N_d\%$)	Normalized percent error ($N_e\%$)
First seepage investigation, May 12, 1998										
Individual reach										
S 0.2 to 0.8	Ks	{-5,300}	12.6	F	13.3	F	0	—	5.3	15.6
S 0.4 to 0.6	Ks	{-3,700}	20.1	P	20.6	G	0	—	2.4	12.8
S .6+.8 to 1.0	Jc	{-600}	[1]33.9	GP	[2]33.6	F	0	—	-.9	-14.4
S 1.0 to 2.0	Jn	4,920	[2]33.6	F	36.6	F	0	—	8.2	15.3
S 2.0 to 3.0	Jn	4,680	36.6	F	32.5	F	0	—	-11.2	-15.1
S 3.0 to 4.0	Jn	2,860	32.5	F	31.3	F	0	—	-3.7	-15.7
S 4.0 to 5.0	Jn	4,190	31.3	F	[2]30.4	GF	0	—	-2.9	-14.3
S 5.0 to 6.0	Tc	1,360	[2]30.4	GF	No Meas	-	0	—	—	6.5
S 6.0 to 7.0	Tc	190	No Meas	-	20.5	F	-15.9	P	—	—
S 7.0 to 8.0	Qu	2,610	20.5	F	26.9	F	0	—	23.8	14.1
S 8.0 to 9.0	Qu	4,580	26.9	F	24.6	F	0	—	-8.6	-15.3
S 9.0 to 10.0	Qu	2,300	24.6	F	25.7	F	0	—	4.3	15.7
	TOTAL:	27,690								
Composite reach										
S 1.0 to 5.0	Jn	4,190	[2]33.6	F	[2]30.4	GF	0	—	-9.5	-13.9
S 5.0 to 7.0	Tc	{1,550}	[2]30.4	GF	20.5	F	-15.9	P	16.5	13.4
S 7.0 to 10.0	Qu	9,490	20.5	F	25.7	F	0	—	20.2	14.4
S 8.0 to 10.0	Qu	6,880	26.9	F	25.7	F	0	—	-4.5	-15.6

Table 4. Error analysis for specified reaches on South Ash Creek, Washington County, Utah—Continued

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of streamflow measure-ment	Down-stream streamflow (Q_{ds}) (ft^3/s)	Accuracy of stream-flow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of streamflow measure-ment	Normalized percent difference (N_d%)	Normalized percent error (N_e%)
Second seepage investigation, August 20, 1998										
Individual reach										
S 0.2 to 0.8	Ks	{-5,300}	2.79	F	2.72	G	0	—	-2.51	-12.87
S 0.4 to 0.6	Ks	{-3,700}	5.48	F	5.45	G	0	—	-.55	-12.97
S .6+.8 to 1.0	Ks/Jc	{-600}	[1]8.17	G	[2]7.10	F	0	—	-13.10	-11.95
S 1.0 to 2.0	Jn	4,920	[2]7.10	F	7.06	F	0	—	-0.56	-15.95
S 2.0 to 3.0	Jn	4,680	7.06	F	6.58	P	0	—	-6.80	-15.46
S 3.0 to 4.0	Jn	2,860	6.58	P	4.72	F	-2.01	G	2.23	14.93
S 4.0 to 5.0	Jn	4,190	4.72	F	3.74	F	0	-	-20.76	-14.34
S 5.0 to 6.0	Tc	1,360	3.74	F	[2]5.60	F	+2.0 e	25%	-2.44	-21.73
S 6.0 to 7.0	Tc	190	[2]5.60	F	.19	P	-5.85	G	7.28	12.51
S 7.0 to 8.0	Qu	2,610	.19	P	3.26	G	0	—	94.17	5.47
S 8.0 to 9.0	Qu	4,580	3.26	G	1.99	P	0	—	-38.96	-9.88
S 9.0 to 10.0	Qu	2,300	1.99	P	1.55	P	0	—	-22.50	-14.23
	TOTAL:	27,690								
Composite reach										
S 1.0 to 5.0	Jn	4,190	[2]7.10	F	3.74	F	-2.01	G	-19.01	-13.63
S 5.0 to 7.0	Qu	1,550	3.74	F	.19	P	+2.00 e -5.85	25% G	4.97	18.33
S 7.0 to 10.0	Qu	9,490	.19	P	1.55	P	0	—	87.74	8.98
S 8.0 to 10.0	Qu	6,880	3.26	G	1.55	P	0	—	-52.45	-8.80
Third seepage investigation, October 1, 1998										
Individual reach										
S 0.2 to 0.8	Ks	{-5,300}	1.73	F	1.65	G	0	—	-4.62	-12.77
S 0.4 to 0.6	Ks	{-3,700}	2.96	F	3.28	F	0	—	9.76	15.22
S .6+.8 to 1.0	Ks/Jc	{-600}	[1]4.93	GF	[2]5.00	F	0	—	1.40	14.41
S 1.0 to 2.0	Jn	4,920	[2]5.00	F	4.87	F	0	—	-2.60	-15.79
S 2.0 to 3.0	Jn	4,680	4.87	F	5.10	F	0	—	4.51	15.64
S 3.0 to 4.0	Jn	2,860	5.10	P	4.08	F	-.56	F	-9.02	-15.28
S 4.0 to 5.0	Jn	4,190	4.08	F	3.08	F	0	—	-24.51	-14.04
S 5.0 to 6.0	Tc	1,360	3.08	F	[2]3.52	GF	+.34	P	2.84	14.27
S 6.0 to 7.0	Tc	190	[2]3.52	P	.02	P	-3.19	F	-8.81	-15.30
S 7.0 to 8.0	Qu	2,610	.02	P	1.68	G	0	—	98.81	5.10
S 8.0 to 9.0	Qu	4,580	1.68	G	.69	P	0	—	-58.93	-8.29
S 9.0 to 10.0	Qu	2,300	.69	P	.50	P	0	—	-27.54	-13.80
	TOTAL:	27,690								
Composite reach										
S 1.0 to 5.0	Jn	4,190	[2]5.00	F	3.08	F	-.56	F	-27.20	-13.82
S 3.5-5.2	Jn	—	.56	F	.34	P	0	—	-39.29	-12.86

Table 4. Error analysis for specified reaches on South Ash Creek, Washington County, Utah—Continued

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft³/s)	Accuracy of streamflow measurement	Downstream streamflow (Q_{ds}) (ft³/s)	Accuracy of streamflow measurement	Streamflow, (+) Inflow (-) Diversion (ft³/s)	Accuracy of streamflow measurement	Normalized percent difference (N_d%)	Normalized percent error (N_e%)
Third seepage investigation, October 1, 1998—Continued										
Composite reach—Continued										
S 5.0 to 7.0	Tc	1,550	3.08	F	.02	P	-3.19	F	-4.05	-15.68
S 7.0 to 10.0	Qu	9,490	.02	P	.50	P	0	—	96.00	8.32
S 8.0 to 10.0	Qu	6,880	1.68	G	.50	P	0	—	-70.24	-7.38
Fourth seepage investigation, October 30, 1998										
Individual reach										
S 0.2 to 0.8	Ks/Jc	{-5,300}	No Meas	—	No Meas	—			—	—
S 0.4 to 0.6	Ks/Jc	{-3,700}	No Meas	—	No Meas	—			—	—
S .6+.8 to 1.0	Jc	{-600}	[1]5.23	G	[2]4.76	GF	0	—	-8.99	-10.92
S 1.0 to 2.0	Jn	4,920	[2]4.76	GF	4.57	G	0	—	-3.99	-11.30
S 2.0 to 3.0	Jn	4,680	4.57	G	6.09	P	0	—	24.96	11.75
S 3.0 to 4.0	Jn	2,860	6.09	P	3.76	G	-.11	P	-36.45	-11.23
S 4.0 to 5.0	Jn	4,190	3.76	G	3.52	F	0	—	-6.38	-12.49
S 5.0 to 6.0	Tc	1,360	3.52	F	[2]3.51	FP	0	—	-.28	-15.98
S 6.0 to 7.0	Tc	190	[2]3.51	FP	.02	G	-3.56	F	1.96	15.83
S 7.0 to 8.0	Qu	2,610	.02	G	1.77	G	0	—	98.87	5.06
S 8.0 to 9.0	Qu	4,580	1.77	G	1.30	P	0	—	-26.55	-10.88
S 9.0 to 10.0	Qu	2,300	1.30	P	1.00	P	0	—	-23.08	-14.15
	TOTAL:	27,690								
Composite reach										
S 1.0 to 5.0	Jn	4,190	[2]4.76	GF	3.52	F	-0.11	P	-23.74	-14.10
S 3.5 to 5.2	Jn	—	.11	P	dry	—	0	—	-100.00	-8.00
S 5.0 to 7.0	Tc	1,550	3.52	F	.02	G	-3.56	F	1.68	15.85
S 7.0 to 10.0	Qu	9,490	.02	G	1.00	P	0	—	98.00	8.10
S 8.0 to 10.0	Qu	6,880	1.77	G	1.00	P	0	—	-43.50	-9.52

[1]Denotes sum of streamflow measured at sites on Mill (S 0.6) and Harmon (S 0.8) Creeks.
[2]Average of two or more streamflow measurements at specified sites.

The purpose of the upper Pintura diversion channel is not known. Water was diverted from the creek on August 20, October 1, and October 30 at S 3.5 into a transmission pipe and ditch for approximately 4,000 ft where the flow returns to the main channel at S 5.2. If the purpose of the upper Pintura diversion channel were to avoid the losing reach between S 4.0 and S 5.0, then a weakly supported by-product of data collected during this investigation indicates that the diversion loses water more efficiently than the natural channel. Evaluation of the only complete set of data collected on October 1 showed that the natural channel between S 4.0 and S 5.0 lost 1.00 ft^3/s (N_d% = -24.51, table 4), while the diversion between S 3.5 and S 5.2 lost 0.22 ft^3/s (N_d% = -39.29, table 4). Data collected for this reach on August 20 and checked on August 21 are incomplete.

The activation of the upper Pintura diversion at S 3.5 (table 3) apparently coincided with the August 20 seepage investigation. Some measurements on that date at sites further downstream (S 5.0 and S 6.0) occurred before, during, and after activation of the diversion. Measurements after about 1530 hours occurred after water was diverted at S 3.5. The activation of the diversion was inferred to be between 0940 hours and 1530 hours from observations and recorded temperatures at S 6.0. For example, when S 5.0 was measured at 0940 hours no return flow was observed from the upper Pintura diversion at S 5.2; however, by 1530 hours, 2.01 ft^3/s was being diverted at S 3.5. Also, the recorded temperature at S 6.0 was 16.0 °C at 1035 hours but increased to 28.5 °C at 1655 hours when it was observed that the channel had a fine layer of bottom sediment and the water was turbid and roily. Interpretation of the August 20 data between S 5.0 and S 7.0 was affected by the activation of the upper Pintura diversion.

Although individual reaches of South Ash Creek that flow through outcrops of the Navajo Sandstone between S 1.0 and S 5.0 show losses and gains that were spatially and temporally variable during each of the four investigations, less water was always measured at the downstream section (S 5.0) than at the upstream section (S 1.0). These seepage losses in the Navajo Sandstone confirm results previously determined during a reconnaissance investigation in October 1995 (table 3; Wilkowske and others, 1998, table 6, p. 52). While the amount of seepage loss between S 1.0 and S 5.0 ranged from 1.13 ft^3/s on October 30 during base flow to 3.2 ft^3/s on May 12 during higher streamflows, the normalized difference exceeded the normalized error only for sets of data collected during lower streamflows measured on August 20, October 1, and October 30. Even though the computed loss for this reach at higher flows on May 12 was relatively large, the normalized difference did not exceed the normalized error.

South Ash Creek between S 5.0 and S 6.0 had a computed gain for October 1 and computed losses for August 20 and October 30, but none exceeded the normalized error (fig. 6, table 4). Site S 5.0 was near the contact of Navajo Sandstone and Claron Formations. South Ash Creek flows across east-dipping bedrock exposures of Claron Formation between S 5.0 to near S 7.0. The computed loss on August 20 assumes that the amount diverted at S 3.5 (2.01 ft^3/s) was approximately equal to the amount of return flow at S 5.2 (2.0 ft^3/s estimated for August 20, table 4, based on measurement on August 21 of 2.04 ft^3/s, table 3), which was dry when S 5.0 was measured in the morning of August 20.

The reach between S 5.0 and S 7.0 gained 6.0 ft^3/s on May 12 and exceeded the normalized error (fig. 6, tables 4). An indeterminate amount of this gain could be attributed to the less-than-ideal measurement site at S 6.5, which was a concrete-lined diversion channel. For better definition of this reach, an intermediate measurement site about 200 ft upstream of the lower Pintura diversion at S 6.0 was added after the May 12 seepage investigation.

The reach between S 6.0 and S 7.0 that includes the lower Pintura diversion at S 6.5 had gains on August 20 and October 30, and a loss on October 1, 1998, but none were greater than the normalized error (fig. 6, table 4). Most of the amount diverted, however, flowed back into the South Ash Creek channel between S 7.0 and S 8.0 (fig. 6, table 4). The seepage analysis of the August 20 investigation for this reach was also affected by the activation of the upper Pintura diversion.

The 2,610-ft reach between S 7.0 and S 8.0 flows on younger Quaternary-aged unconsolidated deposits and consistently gained water during all four investigations. Most, if not all, of the gain was derived from leaks in the lower Pintura diversion that flowed back into South Ash Creek channel above the small, unmapped basalt-flow constriction at S 8.0. All gains were greater than the normalized error (fig. 6, table 4). The amount of gain ranged from 1.66 ft^3/s on October 1 to 6.4 ft^3/s during higher streamflows on May 12 (table 4).

The reach downstream of site S 8.0 to the confluence with Ash Creek east of I-15 at site S 10.0 traverses an alluvium-mantled slope that consists of rounded basalt boulders. Except for a small gain (1.1 ft^3/s at S 10.0, $N_d\% = 4.3$) on May 12 between S 9.0 and S 10.0, the reach between S 8.0 to S 9.0, and S 9.0 to S 10.0 loses water. Seven of the eight measurements made during the four investigations between S 8.0 to S 9.0 and S 9.0 to S 10.0 had losses and six exceeded the normalized error (fig. 6, table 4). Only the loss computed on May 12 between S 8.0 and S 9.0 (2.30 ft^3/s) was less than the normalized error (table 4).

Wet Sandy Creek

Three seepage investigations were completed on a 35,760-ft reach of Wet Sandy Creek on June 1, October 14, and November 4, 1998 (fig. 7, table 5). The reach extends from the farthest motorized access point, about 1 mi upstream of the USGS streamflow-gaging station (09406900) at an altitude of 6,100 ft, to east of I-15 where Wet Sandy Creek flows into Ash Creek at an altitude of 3,660 ft. Wet Sandy Creek flows on westerly dipping undifferentiated Cretaceous-age bedrock that is covered by older unconsolidated Quaternary-age alluvium and debris-flow deposits in the reach between W 1.0 and W 3.0. The Carmel Formation has been mapped in the reach between W 3.0 and 4.0, but outcrops along Wet Sandy Creek were not readily identified because of concealment by unconsolidated alluvial and debris-flow deposits in the channel and on the hillsides. Carmel Formation does crop out just west (right bank, looking downstream) of Wet Sandy Creek in this reach, but its outcrop along the channel was not confirmed. Downstream, Wet Sandy Creek traverses successively older faulted, fractured, and horizontal-to-eastward-dipping rocks

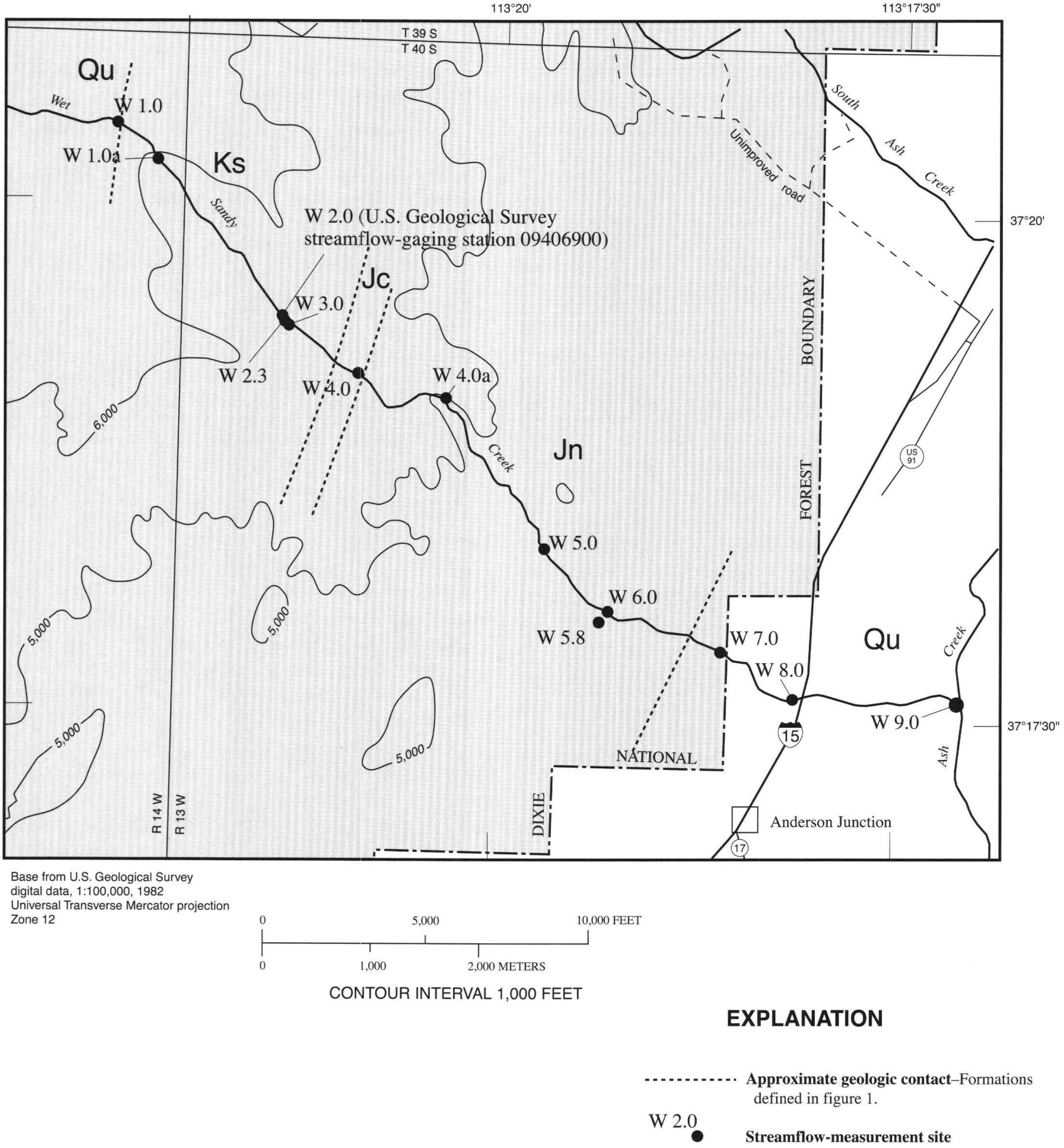


Figure 7. Location of Wet Sandy Creek seepage investigation and streamflow-measurement sites, Washington County, Utah, 1998.

Table 5. Measurements of streamflow, specific conductance, and temperature of water from Wet Sandy Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah

[—, no data available; Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone; Ks, undifferentiated Cretaceous rocks; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; ft, feet; mi, mile]

Site ID: Informal site designation: W 1.0, whole number designation indicates the streamflow-measurement site on Wet Sandy Creek main channel, ascending in downstream order; W 2.3, odd decimal number indicates outflow (diversion) between main channel measurement sites at W 2.0 and W 3.0; W 5.8, even decimal number indicates tributary inflow that enters Wet Sandy Creek between main channel measurement sites at W 5.0 and W 6.0; W 1.0a and W 4.0a are alternate sites and were measured only once during the first and third seepage investigations, respectively.

Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.

Description of site: General description of streamflow-measurement site. USGS, United States Geological Survey; 09406900, number of streamflow-gaging station operated by the USGS.

Streamflow: ft^3/s, cubic feet per second; c, computed (streamflow at diversion W 2.3 is computed by subtracting measured streamflow at W 3.0 from measured streamflow at W 2.0).

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

Temperature: °C, degrees Celsius.

Remarks: Date is month, day, and year that previous data were collected. Q refers to measurement of streamflow.

Site ID	Location	Description of site	Streamflow (ft^3/s)	Specific conductance (µS/cm)	Temperature (°C)	Remarks
		Previous measurements				
	(C-40-13)17acd	Wet Sandy along Jc/Jn contact	1.0	300	11.5	10-06-95
	(C-40-13)21bba	Wet Sandy along Jn/Jk contact	.63	295	12.0	10-06-95
		First seepage investigation, June 1, 1998				
W 1.0a	(C-40-14) 1dac	Wet Sandy Creek ~0.25 mi above Quaternary-Cretaceous contact	4.28	120	15.0	Qu/Ks
W 2.0	(C-40-13) 7bdd	Wet Sandy Creek at USGS gage (09406900)	5.30	200	13.0	Ks
W 2.3	(C-40-13) 7caa	Diversion from Wet Sandy Creek below gage	2.28 c	—	—	Ks; c = W 2.0 minus W 3.0
W 3.0	(C-40-13) 7caa	Wet Sandy Creek below diversion 100 ft below gage	3.02	—	—	Ks
W 4.0	(C-40-13) 7ddb	Wet Sandy Creek 0.6 mi below USGS gage	2.98	185	18.5	Jc?/Jn
W 5.0	(C-40-13)17dda	Wet Sandy Creek in Navajo Sandstone box canyon	2.52	170	22.5	Jn
W 5.8	(C-40-13)21bac	Diversion at first trail crossing before inflow to channel	—	—	—	Jn; no measurement
W 6.0	(C-40-13)21bac	Wet Sandy Creek near lower Navajo Sandstone contact	—	—	—	Jn, no measurement
W 7.0	(C-40-13)21ada	Wet Sandy Creek near small reservoir	2.41	180	26.0	Qu
W 8.0	(C-40-13)22caa	Wet Sandy Creek 600 ft above I-15	2.02	165	15.5	Qu
W 9.0	(C-40-13)23cab	Wet Sandy Creek 75 ft above confluence with Ash Creek	1.30	175	21.0	Qu
		Second seepage investigation, October 14, 1998				
W 1.0	(C-40-14) 1acc	Wet Sandy Creek about 0.25 mi above Quaternary-Cretaceous contact	1.16	105	7.0	Qu/Ks
W 2.0	(C-40-13) 7bdd	Wet Sandy Creek at USGS gage (09406900)	1.88	290	8.0	Ks
W 2.3	(C-40-13) 7caa	Diversion from Wet Sandy Creek below gage	1.97	—	—	Ks
W 3.0	(C-40-13) 7caa	Wet Sandy Creek below diversion 100 ft below gage	dry	—	—	Ks; entire creek is diverted
W 4.0	(C-40-13) 7ddb	Wet Sandy Creek 0.6 mi below USGS gage	dry	—	—	Jc?/Jn
W 5.0	(C-40-13)17dda	Wet Sandy Creek in Navajo Sandstone box canyon	dry	—	—	Jn
W 5.8	(C-40-13)21bac	Diversion at first trail crossing before inflow to channel	1.44	—	—	Jn
W 6.0	(C-40-13)21bac	Wet Sandy Creek near lower Navajo Sandstone contact	1.43	290	12.0	Jn, diverted back to channel
W 7.0	(C-40-13)21ada	Wet Sandy Creek near small reservoir	1.40	280	8.5	Qu
W 8.0	(C-40-13)22caa	Wet Sandy Creek 600 ft above I-15	.92	290	11.5	Qu
W 9.0	(C-40-13)23cab	Wet Sandy Creek 75 ft above confluence with Ash Creek	.93	270	15.0	Qu

Table 5. Measurements of streamflow, specific conductance, and temperature of water from Wet Sandy Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah—Continued

Site ID	Location	Description of site	Streamflow (ft^3/s)	Specific conductance (μS/cm)	Temperature (°C)	Remarks
		Third seepage investigation, November 4, 1998				
W 1.0	(C-40-14) 1acc	Wet Sandy Creek about 0.25 mi above Quaternary-Cretaceous contact	1.02	105	5.0	Qu/Ks
W 2.0	(C-40-13) 7bdd	Wet Sandy Creek at USGS gage (09406900)	1.71	300	8.0	Ks
W 2.3	(C-40-13) 7caa	Diversion from Wet Sandy Creek below gage	dry	—	—	Ks; no diversion
W 3.0	(C-40-13) 7caa	Wet Sandy Creek below diversion 100 ft below gage	1.71c	—	—	Ks; same Q as W 2.0
W 4.0a	(C-40-13) 8cdc	Wet Sandy Creek 1.1 mi below USGS gage	1.51	300	4.0	Jn; different site from 10-14
W 5.0	(C-40-13)17dda	Wet Sandy Creek in Navajo Sandstone box canyon	1.49	305	7.5	Jn
W 5.8	(C-40-13)21bac	Diversion at first trail crossing before inflow to channel	dry	—	—	Jn; no diversion
W 6.0	(C-40-13)21bac	Wet Sandy Creek near lower Navajo Sandstone contact	1.13	305	9.5	Jn
W 7.0	(C-40-13)21ada	Wet Sandy Creek near small reservoir	1.25	260	3.0	Qu
W 8.0	(C-40-13)22caa	Wet Sandy Creek 600 ft above I-15	.83	280	6.5	Qu
W 9.0	(C-40-13)23cab	Wet Sandy Creek 75 ft above confluence with Ash Creek	.88	280	8.0	Qu

of Navajo Sandstone between W 4.0 and W 6.0. About 23,000 ft downstream from W 1.0 between W 6.0 and W 7.0, the channel emerges from a slightly incised box canyon cut into Navajo Sandstone and flows across a broad alluvial fan of younger Quaternary-aged unconsolidated deposits to W 9.0. No Claron Formation, Pine Valley intrusives, or Quaternary basalt flows crop out in the reaches investigated along Wet Sandy Creek.

Gage-height data have been collected at USGS streamflow-gaging station 09406900 (Wet Sandy Creek near Pintura) since December 1993. Comparison of the monthly mean discharge (i.e., arithmetic mean of each daily mean for all days in 1 month) when seepage investigations were performed showed that June 1998 had the second highest monthly mean discharge, and October and November 1998 (water year 1999) had the highest monthly mean discharge for the short-term period of record. Three seepage investigations were performed during wetter-than-normal conditions.

The 8,400-ft reach between W 1.0 and W 2.0 consistently gained water during each of the three seepage investigations. An intermediate site that could have shortened the reach between W 1.0 and W 2.0 was not measured because access through the oak brush was not found. Gains ranged from 0.69 ft^3/s on November 4 to 1.02 ft^3/s on June 1. All computed gains were greater than the normalized error (fig. 8, table 6). No surface-water inflows were identified between the two sites, and the specific-conductance data indicate that the inflow probably was accretion from a ground-water source that has a sufficiently long flow path and residence time to increase specific conductance. Specific conductance at W 1.0 ranged from 105 μS/cm to 120 μS/cm, and at W 2.0 from 200 μS/cm to 300 μS/cm (table 5). Between W 1.0 and W 3.0, Wet Sandy Creek flows across outcrops mapped as undifferentiated Cretaceous Formations that were concealed by rubble from debris flows and alluvium of the older Quaternary alluvial deposits. Bedrock outcrops were not observed in the channel.

A diversion at W 2.3 removes water for irrigation about 100 ft downstream of the USGS gage at W 2.0. For each of the three investigations, the amount and status of the diversion were different. On June 1, 2.28 ft^3/s was calculated to be diverted; on October 14 all the water was diverted; and on November 4 no water was diverted. The October 14 investigation was a loss-gain assessment of the diversion between W 2.3 and W 5.8 that lost 0.53 ft^3/s, not the natural channel, which was dry. The loss exceeded the normalized error.

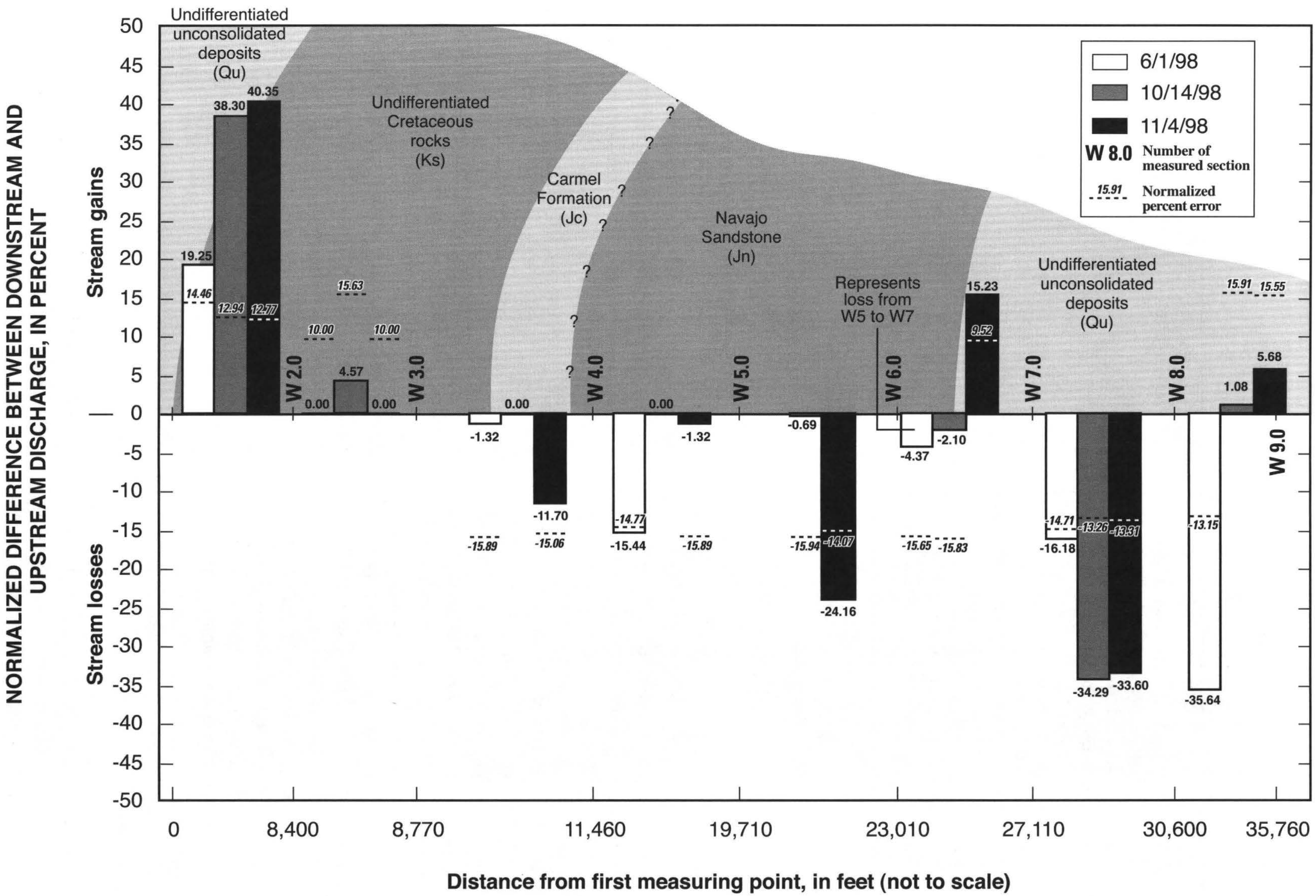


Figure 8. Gaining and losing reaches of Wet Sandy Creek during three seepage investigations in Washington County, Utah, 1998.

Table 6. Error analysis for specified reaches on Wet Sandy Creek, Washington County, Utah

[—, no data available; Individual reach, specifies the interval between consecutive upstream and downstream streamflow-measurement sites; Composite reach, specifies the interval between specified streamflow-measurement sites, which are combined to assess the loss or gain of a specific hydrogeologic unit]

Site ID: Informal site designation. The first number specifies the upstream streamflow-measurement site and the second number the downstream streamflow-measurement site. Interval between specified sites is the reach. See table 5 for additional information.

Hydrogeologic unit: Description of rock formation that outcrops at streamflow-measurement site for specified reach: Jc, Jurassic Carmel Formation; Jn, Navajo Sandstone; Ks, undifferentiated Cretaceous rocks; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; Tc, Tertiary Claron Formation; Ti, Tertiary Pine Valley laccolithic intrusive rocks.

Distance: ft, feet. Distance of reach between streamflow-measurement sites. TOTAL is distance, in feet, of all reaches of seepage investigation; ~, approximate.

Streamflow: Q_{us}, streamflow at upstream measurement site in reach; Q_{ds}, streamflow at downstream site; Inflow from tributaries designated with (+) sign; Diversions designated with (-) sign; ft^3/s, cubic feet per second; No Meas, streamflow was not measured at site; c, computed by subtracting upstream from downstream streamflow; s, same streamflow as W 2.0.

Accuracy of streamflow measurement: A qualitative evaluation of several factors, such as cross-section and velocity uniformity, and stream bed conditions, that could, in the opinion of the streamgager, affect the accuracy of the measuremen: G, good, measured streamflow is within 5 percent of "true" streamflow; F, fair, streamflow is within 8 percent of "true" streamflow; P, poor, measured streamflow is more than 8 percent of the "true" streamflow.

Normalized percent difference: $N_d\%$, see Equation 2 for definition.

Normalized percent error: $N_e\%$, see Equation 3 for definition.

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of stream-flow measure-ment	Downstream streamflow (Q_{ds}) (ft^3/s)	Accuracy of streamflow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of streamflow measure-ment	Normalized percent difference ($N_d\%$)	Normalized percent error ($N_e\%$)
First seepage investigation, June 1, 1998										
Individual reach										
W 1.0	Qu	0	No Meas	—	4.28	F	0	—	—	—
W 1.0-2.0	Ks	8,400	4.28	F	5.30	F	0	—	19.25	14.46
W 2.0-3.0	Ks	370	5.30	F	3.02	F	-2.28 c	F	0	16.00
W 3.0-4.0	Ks/Jc/Jn	2,690	3.02	F	2.98	F	0	—	-1.32	-15.89
W 4.0-5.0	Jn	8,250	2.98	F	2.52	F	0	—	-15.44	-14.77
W 5.0-6.0	Jn	3,300	2.52	F	No Meas	—	0	—	—	—
W 6.0-7.0	Qu	4,100	No Meas	—	2.41	P	0	—	—	—
W 7.0-8.0	Qu	3,490	2.41	P	2.02	P	0	—	-16.18	-14.71
W 8.0-9.0	Qu	5,160	2.02	P	1.30	P	0	—	-35.64	-13.15
	TOTAL	35,760								
Composite reach										
W 1.0-3.0	Ks	8,770	4.28	F	3.02	F	-2.28 c	F	19.25	14.46
W 3.0-7.0	Ks/Qu	18,340	3.02	F	2.41	P	0	—	-20.20	-14.38
W 4.0-7.0	Jn/Qu	15,650	2.98	F	2.41	P	0	—	-19.13	-14.47
W 5.0 -7.0	Jn/Qu	7,400	2.52	F	2.41	P	0	—	-4.37	-15.65
W 7.0-9.0	Qu	8,650	2.41	P	1.30	P	0	—	-46.06	-12.32
Second seepage investigation, October 14, 1998										
Individual reach										
W 1.0	Qu	0	No Meas	—	1.16	F	0	—	0	0
W 1.0-2.0	Ks	8,400	1.16	F	1.88	F	0	—	38.30	12.94
W 2.0-3.0	Ks	370	1.88	F	0	-	-1.97	F	4.57	15.63
W 3.0-4.0	Ks/Jc/Jn	2,690	0	—	0	-	0	—	0	0
W 4.0-5.0	Jn	8,250	0	—	0	-	0	—	0	0
W 5.0-6.0	Jn	3,300	0	—	1.43	F	+1.44	F	-0.69	-15.94
W 6.0-7.0	Qu	4,100	1.43	F	1.40	P	0	—	-2.10	-15.83
W 7.0-8.0	Qu	3,490	1.40	P	.92	P	0	—	-34.29	-13.26

Table 6. Error analysis for specified reaches on Wet Sandy Creek, Washington County, Utah—Continued

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft³/s)	Accuracy of stream-flow measure-ment	Downstream streamflow (Q_{ds}) (ft³/s)	Accuracy of streamflow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft³/s)	Accuracy of streamflow measure-ment	Normalized percent difference (N_d%)	Normalized percent error (N_e%)
Second seepage investigation, October 14, 1998—Continued										
Individual reach—Continued										
W 8.0-9.0	Qu	5,160	.92	P	.93	P	0	—	1.08	15.91
	TOTAL	35,760								
Composite reach										
W 1.0-3.0	Ks	8,770	1.16	F	0	—	+1.97	F	41.12	12.71
W 2.3-5.8	Ks/Jn	~14,240	1.97	F	1.44	F	0	—	-26.90	-13.85
W 4.0-6.0	Jn	11,550	0	—	1.43	F	+1.44	F	-.69	-15.94
W 5.0-7.0	Jn/Qu	7,400	0	—	1.40	P	+1.44	F	-2.78	-15.78
W 7.0-9.0	Qu	8,650	1.40	P	.93	P	0	—	-33.57	-13.31
Third seepage investigation, November 4, 1998										
Individual reach										
W 1.0	Qu	0	No Meas	-	1.02	P	0	—	—	—
W 1.0-2.0	Ks	8,400	1.02	P	1.71	P	0	—	40.35	12.77
W 2.0-3.0	Ks	370	1.71	P	1.71 s	P	0	—	0	16.00
W 3.0-4.0a	Ks/Jc/Jn	~4,500	1.71 s	P	1.51	F	0	—	-11.70	-15.06
W 4.0a-5.0	Jn	~6,440	1.51	F	1.49	P	0	—	-1.32	-15.89
W 5.0-6.0	Jn	3,300	1.49	P	1.13	P	0	—	-24.16	-14.07
W 6.0-7.0	Qu	4,100	1.13	P	1.25	P	0	—	9.60	15.23
W 7.0-8.0	Qu	3,490	1.25	P	.83	P	0	—	-33.60	-13.31
W 8.0-9.0	Qu	5,160	.83	P	.88	P	0	—	5.68	15.55
	TOTAL	35,760								
Composite reach										
W 1.0-3.0	Ks	8,770	1.02	P	1.71 s	P	0	—	40.35	12.77
W 2.3-5.8	Ks/Jn	~14,240	dry	—	dry	—	0	—	—	—
W 3.0-6.0	Ks/Jn	14,240	1.71 c	P	1.13	P	0	—	-33.92	-13.29
W 4.0a-6.0	Jn	~9,740	1.51	F	1.13	F	0	—	-25.17	-13.99
W 5.0-7.0	Jn/Qu	7,400	1.49	P	1.25	P	0	—	-16.11	-14.71
W 7.0-9.0	Qu	8,650	1.25	P	.88	P	0	—	-29.60	-13.63

The natural channel through the canyon is incised in the Navajo Sandstone in the vicinity of sites W 4.0, W 5.0, and upstream of W 6.0. The reach between W 4.0 and 5.0 was dry on October 14, and lost water on June 1 and November 4. Only the June 1 loss exceeded the normalized error (table 6).

One set of seepage data was collected for the reach between W 5.0 and W 6.0. On November 4 this reach lost 0.36 ft³/s, which was greater than the normalized error (fig. 8, table 6). The site at W 6.0 was added after the June 1 investigation and the natural channel upstream of W 6.0 was dry on October 14 when all the water was diverted.

The reach between W 6.0 and W 7.0 had an insignificant loss (N_d% less than N_e%) on October 14 and an insignificant gain on November 4. No measurement was determined at W 6.0 on June 1, but the 7,400-ft reach between W 5.0 and W 7.0 had a loss of 0.11 ft³/s, which was less than the normalized error (table 6).

Wet Sandy Creek flows on unconsolidated deposits between W 7.0 to W 8.0 and consistently lost water during all three investigations. The amount of water lost ranged from 0.39 ft³/s on June 1 to 0.48 ft³/s on October 14. All three losses exceeded the normalized error (fig. 8, table 6).

At higher flows, the reach between W 8.0 and W 9.0 lost 0.72 ft³/s on June 1, which exceeded the normalized error. Gains of 0.01 and 0.05 ft³/s were computed on October 14 and November 4, respectively, when streamflow was near base flow though both were less than the normalized error (fig. 8, table 6).

Leeds Creek

Three seepage investigations were completed on a 33,690-ft reach of Leeds Creek that extends from the U.S. Forest Service Oak Grove campground downstream to the USGS gage (09408000) about 2 mi northwest of the town of Leeds. Elevation drops 2,460 ft from an altitude of 6,460 ft at the campground to 4,000 ft at the gage. Streamflow was measured at eight main channel sites and at five or six tributary inflows (fig. 9, table 7). There were no diversions in any reach investigated. Seepage investigations were completed on May 19, October 2, and October 15, 1998 (table 7). The May 19 investigation was completed during high-flow conditions.

Monthly mean discharge at the USGS gage for May 1998 was 22.2 ft^3/s and represents the sixth highest May streamflow recorded during 34 years of record. For comparison, mean monthly discharge for May during the period of record (water years 1965-98) was 11.1 ft^3/s. Monthly mean discharge for October 1998 (water year 1999) was 7.59 ft^3/s and represents the second highest October streamflow for 35 years of record. October mean monthly discharge was 4.09 ft^3/s for the period of record (water years 1965-99). Wetter-than-normal conditions prevailed when these seepage data were collected.

Gage height data were recorded every 15 minutes at the USGS gage. All three seepage investigations were done during periods of nearly stable gage height and flow conditions. Recorded gage height ranged from 0.02 ft for the duration of the May 19 investigation to 0.01 ft at 1300 and 1315 hours on October 2. No gage height variation was recorded for October 15.

In the 5,090-ft reach between the upper two main channel sites at LD 1.0 near Oak Grove campground and LD 2.0 just downstream of Pig Creek (table 7), Leeds Creek flows on older unconsolidated alluvial and debris flow deposits eroded from the Pine Valley laccolith. Seepage data were insufficient in this reach for a complete loss-gain assessment on May 19 but there were gains on October 2 and 15. The amount of loss or gain for May 19 was indeterminate because inflow from Pig Creek was not measured. Inflow from Pig Creek was measured on October 2 and 15, and nearly uniform gains of 0.82 ft^3/s and 0.74 ft^3/s were measured. Both gains were greater than the normalized error (fig. 10, table 8).

The 4,970-ft reach between LD 2.0 and LD 3.0 had a loss during higher streamflows on May 19 and gains during the two investigations at lower streamflows (fig. 10, table 8). Leeds Creek in this reach flows on progressively more incised older unconsolidated alluvial and debris-flow deposits. This reach lost 2.33 ft^3/s and gained 0.86 ft^3/s and 0.26 ft^3/s on May 19, October 2, and October 15, respectively, but none exceeded the normalized error (fig. 10, table 8).

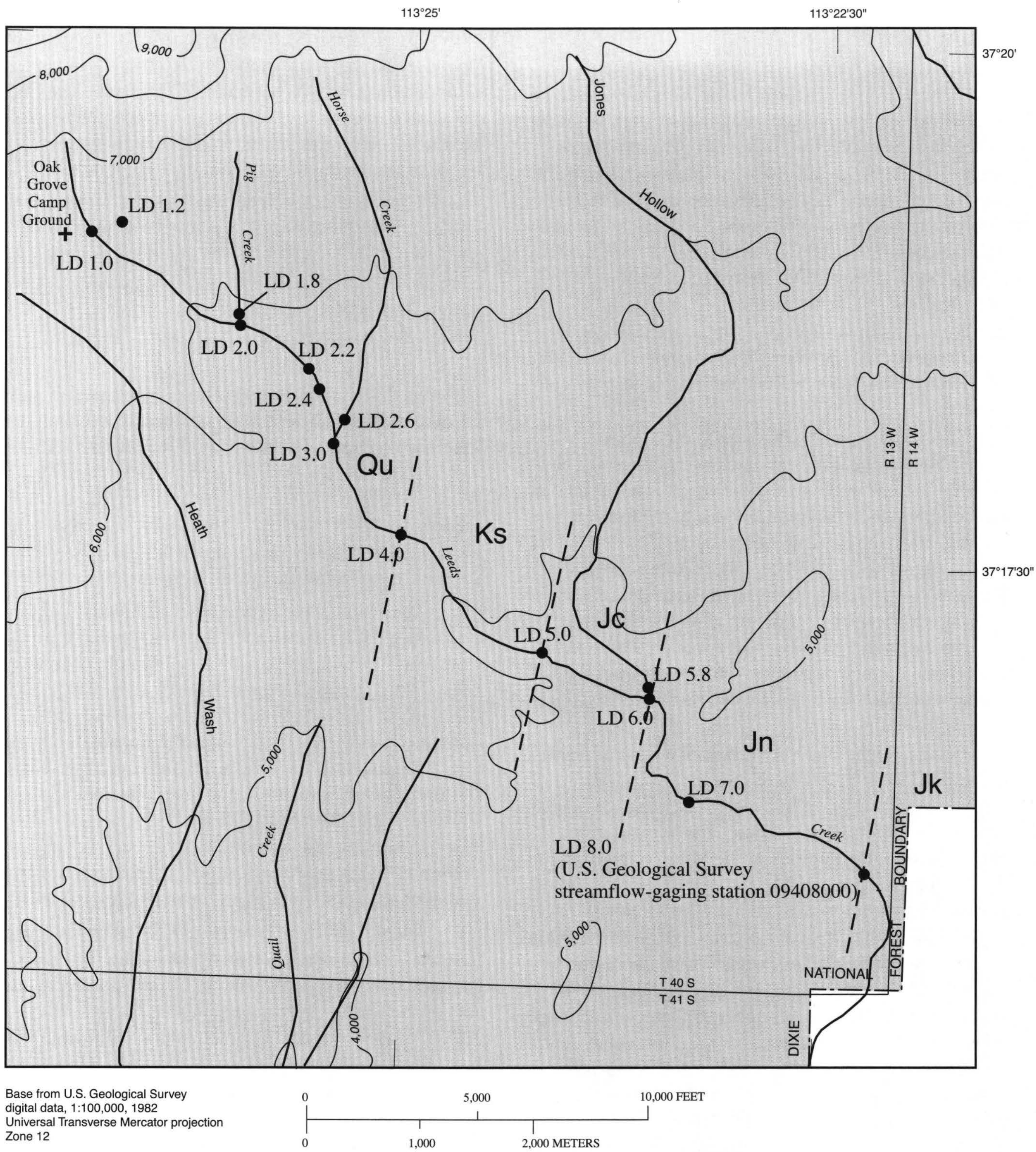
The 3,630-ft reach between LD 3.0 and LD 4.0 gained 1.5 ft^3/s on May 19, lost 0.02 ft^3/s on October 2, and lost 0.22 ft^3/s on October 15, but none exceeded the normalized error (fig. 10, table 8). The contact between the unconsolidated alluvial deposits and the undifferentiated Cretaceous rocks is at LD 4.0.

The 5,940-ft reach between LD 4.0 and LD 5.0 flows on thin unconsolidated fluvial deposits that overlie outcrops of undifferentiated Cretaceous rocks. This reach had computed gains for all three investigations of 1.3 ft^3/s on May 19, 0.07 ft^3/s on October 2, and 0.69 ft^3/s on October 15, but all were less than the normalized error (fig. 10, table 8). Sandstone and siltstone of the undifferentiated Cretaceous rocks likely was a source for surface-water gains in this reach.

The 3,260-ft reach between LD 5.0 and LD 6.0 was entirely within the outcrop of the Carmel Formation. This reach had minor losses of 0.14 ft^3/s on May 19 and 0.02 ft^3/s on October 2, and a gain of 0.24 ft^3/s on October 15. Neither the computed losses nor the computed gain were greater than the normalized error (fig. 10, table 8). The gypsiferous shale and gypsum of the Temple Cap Formation that lies between the Carmel Formation and Navajo Sandstone in this area (David Hacker, Kent State University doctoral candidate, oral commun., 1995) probably causes the high specific-conductance value of water from Jones Hollow (table 7).

The 4,630-ft reach between LD 6.0 and LD 7.0 and the 6,170-ft reach between LD 7.0 and LD 8.0 are incised in the Navajo Sandstone. LD 6.0 was at the contact of the Carmel Formation and Navajo Sandstone; LD 7.0 was just upstream of a mapped fault (see Hurlow, 1998, pl. 1), and LD 8.0 was near the contact of the Navajo Sandstone and underlying Kayenta Formation at the USGS gage (09408000). On May 19, the reach between LD 6.0 and LD 7.0 gained 1.0 ft^3/s. On October 2 and 15 the reach between LD 6.0 and LD 7.0 lost 0.12 ft^3/s and 0.51 ft^3/s, respectively. All computed losses and gains were less than the normalized error (fig. 10, table 8).

The reach between LD 7.0 and LD 8.0 lost 2.6 ft^3/s on May 19, gained 0.51 ft^3/s on October 2, and gained 0.30 ft^3/s on October 15. Neither the loss nor the gains exceeded the normalized error (fig. 10, table 8).



EXPLANATION

- - - - - - - - - - - - **Approximate geologic contact**–Formations defined in figure 1.

LD 7.0
● **Streamflow-measurement site**

Figure 9. Location of Leeds Creek seepage investigation and streamflow-measurement sites, Washington County, Utah, 1998.

Table 7. Measurements of streamflow, specific conductance, and temperature of water from selected sites on Leeds Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah

[—, no data available; Jc, Jurassic Carmel Formation and Temple Cap Formation; Jk, Kayenta Formation; Jn, Navajo Sandstonee: Ks, undifferentiated Cretaceous rocks; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; ft, feet; mi, mile]

Site ID: Informal site designation: LD 1.0, whole number designation indicates the streamflow-measurement site on Leeds Creek main channel, measured in downstream order; LD 1.2, even decimal number indicates tributary inflow that enters Leeds Creek downstream of main channel measurement site at LD 1.0 but upstream of main channel measurement site at LD 2.0.
Location: See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah.
Description of site: General description of streamflow-measurement site location. USGS, United States Geological Survey; USFS, United States Forest Service; 09408000, number of streamflow-gaging station operated by the USGS.
Streamflow: ft^3/s, cubic feet per second; e, estimated.
Specific conductance: $\mu S/cm$, microsiemens per centimeter at 25 degrees Celsius.
Temperature: °C, degrees Celsius.
Remarks: Date is month, day, and year that previous data were collected. Q refers to measurement of streamflow. Time is reported in military format for local daylight-savings time. Pygmy and Price refer to current meters.

Site ID	Location	Description of site	Streamflow (ft^3/s)	Specific conductance ($\mu S/cm$)	Temperature (°C)	Remarks
		Previous measurements				
	(C-40-14)26acc	Leeds Creek along Jc/Jn contact	6.65	260	8.5	10-07-95
			4.99	285	6.0	12-07-95
	(C-40-14)36adc	Leeds Creek at USGS gage (09408000)	5.09	—	—	12-07-95
	(C-40-14)36add	Leeds Creek along Jn/Jk contact	5.27	265	7.0	10-07-95
			7.28	285	5.0	12-07-95
		First seepage investigation, May 19, 1998				
LD1.0	(C-40-14)17baa	Leeds Creek near Oak Grove Campground	3.19	225	10.0	Qu
LD1.2	(C-40-14) 8dcd	Inflow from north near USFS (Dan Spr 4) sign	3.32	77	10.0	Qu
LD1.8	(C-40-14)16bcd	Pig Creek near confluence with Leeds Creek	—	—	—	Qu; did not measure
LD2.0	(C-40-14)16bdc	Leeds Creek below Pig Creek inflow	10.8	180	11.5	Qu
LD2.2	(C-40-14)16dbd	Unnamed tributary from the south at culvert	.08	—	—	Qu
LD2.4	(C-40-14)16dca	Unnamed tributary inflow from the south	1.08	250	11.5	Qu
LD2.6	(C-40-14)16ddc	Horse Creek 250 ft above confluence with Leeds Creek	7.97	225	13.0	Qu
LD3.0	(C-40-14)21aab	Leeds Creek 40 ft below USFS bridge	17.6	210	10.5	Qu
LD4.0	(C-40-14)22cab	Leeds Creek at Qu/Ks contact	19.1	215	11.5	Qu/Ks
LD5.0	(C-40-14)26bbc	Leeds Creek at Ks/Jc contact	20.4	180	9.0	Ks/Jc
LD5.8	(C-40-14)26acc	Jones Hollow 75 ft above confluence with Leeds Creek	.54	660	12.5	Jc
LD6.0	(C-40-14)26acc	Leeds Creek below Jones Hollow at Jc/Jn	20.8	235	11.0	Jc/Jn
LD7.0	(C-40-14)35aab	Leeds Creek at midpoint Jn outcrop, above fault	21.8	230	12.0	Jn
LD8.0	(C-40-14)36adc	Leeds Creek at USGS gage (09408000)	19.2	230	14.0	Jn/Jk/Qu
		Second seepage investigation, October 2, 1998				
LD1.0	(C-40-14)17baa	Leeds Creek near Oak Grove Campground	.01e	410	10.0	Qu
LD1.2	(C-40-14) 8dcd	Inflow from north near USFS 'Dan Spr 4' sign	.72	80	8.0	Qu
LD1.8	(C-40-14)16bcd	Pig Creek near confluence with Leeds Creek	1.27	—	10.0	Qu
LD2.0	(C-40-14)16bdc	Leeds Creek below Pig Creek inflow	2.82	160	10.0	Qu
LD2.2	(C-40-14)16dbd	Unnamed tributary from the south at culvert	—	—	—	Qu; did not measure
LD2.4	(C-40-14)16dca	Unnamed tributary inflow from the south	—	—	—	Qu; did not measure
LD2.6	(C-40-14)16ddc	Horse Creek 250 ft above confluence with Leeds Creek	3.97	270	9.0	Qu
LD3.0	(C-40-14)21aab	Leeds Creek 40 ft below USFS bridge	7.94	235	10.0	Qu; measured at 1145 hours
			7.36	235	11.5	Qu; measured at 1345 hours
LD4.0	(C-40-14)22cab	Leeds Creek at Qu/Ks contact	7.63	240	10.5	Qu/Ks
LD5.0	(C-40-14)26bbc	Leeds Creek at Ks/Jc contact	7.53	235	8.5	Ks/Jc; measured at 0900 hours
LD5.0	(C-40-14)26bbc	Leeds Creek at Ks/Jc contact	7.87	245	11.5	Ks/Jc; measured. at 1335 hours
LD5.8	(C-40-14)26acc	Jones Hollow 75 ft above confluence with Leeds Creek	.20	610	12.0	Jc

Table 7. Measurements of streamflow, specific conductance, and temperature of water from selected sites on Leeds Creek that discharges from the east side of the Pine Valley Mountains in Washington County, Utah—Continued

Site ID	Location	Description of site	Stream-flow (ft^3/s)	Specific conduct-ance (μS/cm)	Temper-ature (°C)	Remarks
		Second seepage investigation, October 2, 1998—Continued				
LLD6.0	(C-40-14)26acc	Leeds Creek below Jones Hollow at Jc/Jn	7.88	260	9.5	Jc/Jn
LD7.0	(C-40-14)35aab	Leeds Creek at midpoint Jn outcrop, above fault	7.76	260	11.0	Jn
LD8.0	(C-40-14)36adc	Leeds Creek at USGS gage (09408000)	8.27	225	12.5	Jn/Jk/Qu
		Third seepage investigation, October 15, 1998				
LD1.0	(C-40-14)17baa	Leeds Creek near Oak Grove Campground	.06	305	9.5	Qu
LD1.2	(C-40-14) 8dcd	Inflow from north near USFS (Dan Spr 4) sign	.44	83	6.5	Qu
LD1.8	(C-40-14)16bcd	Pig Creek near confluence with Leeds Creek	1.03	130	9.0	Qu
LD2.0	(C-40-14)16bdc	Leeds Creek below Pig Creek inflow	2.27	160	8.5	Qu
LD 2.2	(C-40-14)16dcd	Unnamed tributary inflow from the south	.04	255	10.5	Qu
LD 2.4	(C-40-14)16dca	Unnamed tributary inflow from the south	dry	—	—	Qu
LD2.6	(C-40-14)16ddc	Horse Creek 250 ft above confluence with Leeds Creek	4.02	280	8.0	Qu
LD3.0	(C-40-14)21aab	Leeds Creek 40 ft below USFS bridge	6.52	250	8.5	Qu; measured at 1100 hours
			6.57	—	—	Qu, measured at1345 hours; Price
			6.67	245	10.5	Qu, measured at1435 hours; Pygmy
LD4.0	(C-40-14)22cab	Leeds Creek at Qu/Ks contact	6.37	255	9.0	Qu/Ks
LD5.0	(C-40-14)26bbc	Leeds Creek at Ks/Jc contact	7.42	260	7.5	Ks/Jc; measured at 0915 hours
			6.71	260	10.0	Ks/Jc; measured at 1315 hours
LD5.8	(C-40-14)26acc	Jones Hollow 75 ft above confluence with Leeds Creek	.18	610	9.0	Jc
LD6.0	(C-40-14)26acc	Leeds Creek below Jones Hollow at Jc/Jn	7.48	270	8.0	Jc/Jn
LD7.0	(C-40-14)35aab	Leeds Creek at midpoint Jn outcrop, above fault	6.97	265	9.0	Jn
LD8.0	(C-40-14)36adc	Leeds Creek at USGS gage (09408000)	7.27	265	9.5	Jn/Jk/Qu

The computed seepage losses or gains for the Navajo Sandstone outcrop between LD 6.0 and LD 8.0 indicate that two of the three investigations had less water measured in the channel at the downstream section (LD 8.0) than at the upstream section (LD 6.0). The normalized differences for both losses and one gain were less than the normalized error between LD 6.0 and LD 8.0. At higher streamflows on May 19, the gain between LD 6.0 and LD 7.0 was accompanied by a loss at the successive downstream reach between LD 7.0 and LD 8.0. This trend was reversed for measurements made at lower streamflows. This dynamic interaction between the surface and ground water is not fully explained by variable stage and seasonality.

INTERPRETATION OF SEEPAGE INVESTIGATIONS

To determine if individual loss-gain results among the creeks were related to geologic features such as rock formation or fault zones, an assessment of the loss or gain for each creek where it crosses a specific rock outcrop or deposit was required. The four hydrogeologic units assessed are (1) Navajo Sandstone; (2) undifferentiated and unconsolidated Quaternary-age alluvial-fan and debris-flow deposits; (3) igneous rocks that include the intrusive Pine Valley laccolithic rocks of Tertiary age and the extrusive basalt flows of Quaternary age; and (4) sedimentary rocks other than the Navajo Sandstone that include Carmel Formation, undifferentiated Cretaceous rocks, and Claron Formation.

Navajo Sandstone

Navajo Sandstone crops out along each of the four creeks, though the relative position of the outcrop varies from the uppermost reach on Leap Creek to the lowermost reach on Leeds Creek. For those reaches of the 4 creeks that traverse outcrops of Navajo Sandstone (i.e., LP 1.0 to LD 3.0, S 1.0 to S 5.0, W 4.0 to W 6.0 (or W 7.0 on June 1), and LD 6.0 to LD 8.0), data from 11 of the 13 seepage investigations (i.e., 3 on Leap Creek, 4 on South Ash Creek, 3 on Wet Sandy Creek, and 3 on Leeds Creek) had less water at or near the

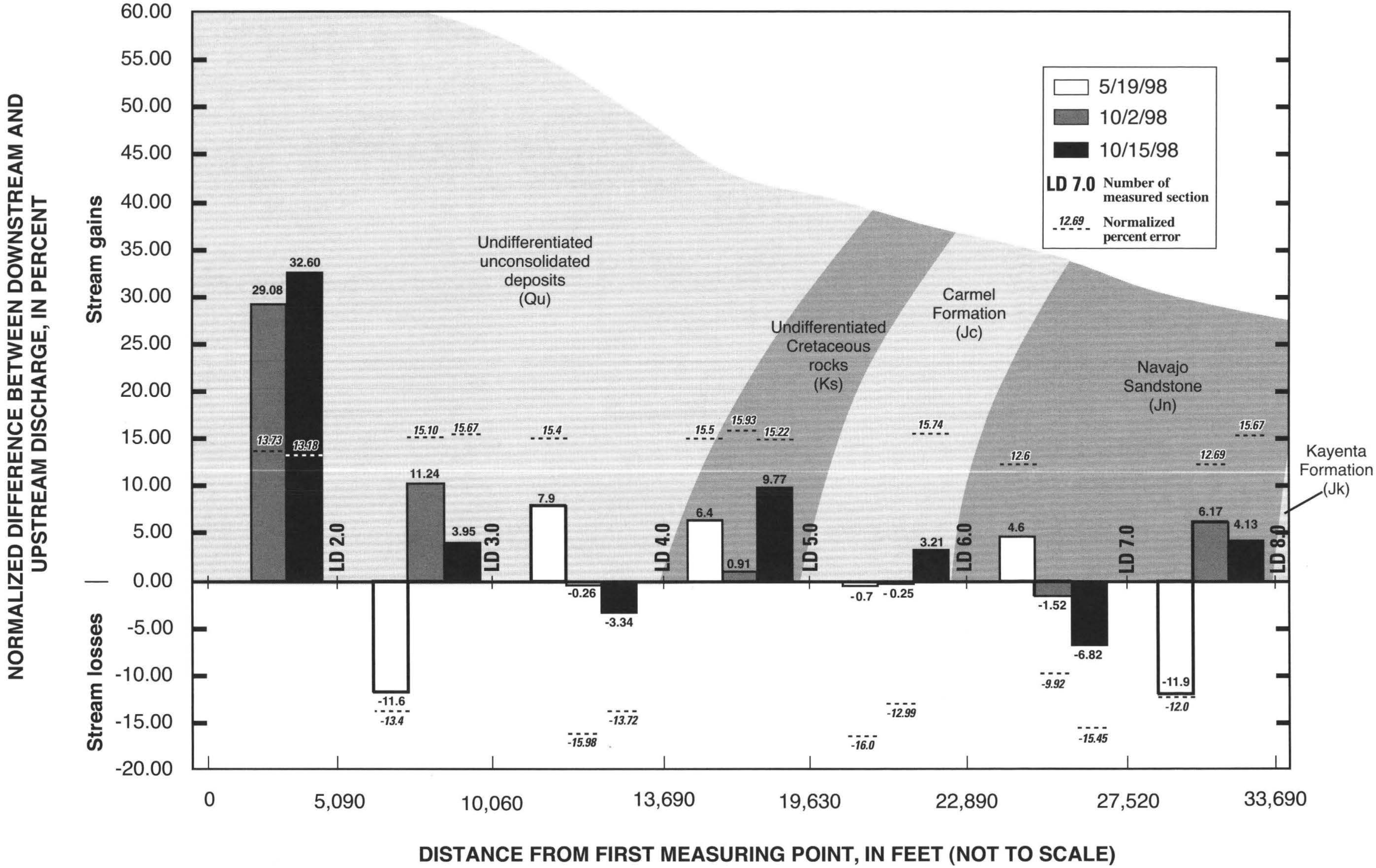


Figure 10. Gaining and losing reaches of Leeds Creek during three seepage investigations in Washington County, Utah,1998.

Table 8. Error analysis for specified reaches on Leeds Creek, Washington County, Utah

[—, no data available; Individual reach, specifies the interval between consecutive upstream and downstream streamflow-measurement sites; Composite reach, specifies the interval between specified streamflow-measurement sites, which are combined to assess the loss or gain of a specific hydrogeologic unit]

Site ID: Informal site designation. The first number specifies the upstream streamflow-measurement site and the second number the downstream streamflow-measurement site. Interval between specified sites is the reach. See table 7 for additional information.

Hydrogeologic unit: Description of rock formation that outcrops at each streamflow-measurement site for specified reach: Jc, Jurassic Carmel Formation and Temple Cap Formation; Jn, Navajo Sandstone; Ks, undifferentiated Cretaceous rocks; Qb, Quaternary basalt flows; Qu, undifferentiated Quaternary deposits including fluvial, alluvial fan, colluvial, and sediments of mass movement from debris flows; Tc, Tertiary Claron Formation; Ti, Tertiary Pine Valley laccolithic intrusive rocks.

Distance: ft, feet. Distance of reach between streamflow-measurement sites. TOTAL distance, in feet, of all reaches of seepage investigation.

Streamflow: Q_{us}, upstream measurement site in reach; Q_{ds}, streamflow at downstream site; Inflow from tributaries designated with (+) sign and represents total of one or more inflows between upstream and downstream sites; Diversions designated with (-) sign; ft^3/s, cubic feet per second; No Meas, streamflow was not measured at site; ?, streamflow at Pig Creek inflow not measured, no error analysis for that reach; e, estimated.

Accuracy of streamflow measurement: A qualitative evaluation of several factors, such as cross-section and velocity uniformity, and stream bed conditions, that could, in the opinion of the streamgager, affect the accuracy of the measurement: G, good, measured streamflow is within 5 percent of "true" streamflow; F, fair, within 8 percent; P, poor, measured streamflow is more than 8 percent of the "true" streamflow; e, estimated, streamflow is probably within 25 percent of "true" streamflow. For a site with two measurements and two accuracy ratings, the average of the two ratings is used. For example, if two measurements were rated F and P, the average accuracy would still be 8 percent.

Normalized percent difference: $N_d\%$, see Equation 2 for definition.

Normalized percent error: $N_e\%$, see Equation 3 for definition.

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of stream-flow measure-ment	Downstream streamflow (Q_{ds}) (ft^3/s)	Accuracy of stream-flow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of stream-flow measure-ment	Normalized percent difference ($N_d\%$)	Normalized percent error ($N_e\%$)
			First seepage investigation, May 19, 1998							
Individual reach										
LD 1.0	Qu	0	No Meas	-					—	—
LD 1.0-2.0	Qu	5,090	3.19	F	10.8		+3.32+ ?	F	—	—
LD 2.0-3.0	Qu	4,970	10.8	G	17.6		+9.13	FP	-11.6	-13.4
LD 3.0-4.0	Qu	3,630	17.6	F	19.1	F	0	-	7.9	15.4
LD 4.0-5.0	Ks	5,940	19.1	F	20.4	F	0	-	6.4	15.5
LD 5.0-6.0	Jc	3,260	20.4	F	20.8	F	+.54	P	-.7	-16.0
LD 6.0-7.0	Jn	4,630	20.8	F	21.8	G	0	-	4.6	12.6
LD 7.0-8.0	Jn	6,170	21.8	G	19.2	P	0	-	-11.9	-12.0
	TOTAL	33,690								
Composite reach										
LD 1.0-3.0	Qu	10,060	3.19		17.6		+9.13+ ?		—	—
LD 1.0-4.0	Qu	13,690	3.19		19.1		+9.13+ ?		—	—
LD 2.0-4.0	Qu	8,600	10.8		19.1		+9.13		-4.2	-14.0
LD 6.0-8.0	Jn	10,800	20.8		19.2		0	-	-7.7	-15.4
			Second seepage investigation, October 2, 1998							
Individual reach										
LD 1.0	Qu	0	0	-	.01e	25%	0	-	—	—
LD 1.0-2.0	Qu	5,090	.01e	25%	2.82	P	+1.99	P	29.08	13.73
LD 2.0-3.0	Qu	4,970	2.82	P	[1]7.65	F	+3.97	F	11.24	15.10
LD 3.0-4.0	Qu	3,630	[1]7.65	F	7.63	F	0	-	-.26	-15.98

Table 8. Error analysis for specified reaches on Leeds Creek Washington County, Utah—Continued

Site ID	Hydro-geologic unit	Distance (ft)	Upstream streamflow (Q_{us}) (ft^3/s)	Accuracy of stream-flow measure-ment	Downstream streamflow (Q_{ds}) (ft^3/s)	Accuracy of stream-flow measure-ment	Streamflow, (+) Inflow (-) Diversion (ft^3/s)	Accuracy of stream-flow measure-ment	Normalized percent difference (N_d%)	Normalized percent error (N_e%)
Second seepage investigation, October 2, 1998—Continued										
Individual reach—Continued										
LD 4.0-5.0	Ks	5,940	7.63	F	[1]7.70	F	0	-	.91	15.93
LD 5.0-6.0	Jc	3,260	[1]7.70	F	7.88	G	+.20	P	-.25	-12.99
LD 6.0-7.0	Jn	4,630	7.88	G	7.76	G	0	-	-1.52	-9.92
LD 7.0-8.0	Jn	6,170	7.76	G	8.27	F	0	-	6.17	12.69
	TOTAL	33,690								
Composite reach										
LD 1.0-3.0	Qu	10,060	.01e	25%	[1]7.65	F	+5.96	FP	21.96	14.27
LD 1.0-4.0	Qu	13,690	.01e	25%	7.63	F	+5.96	FP	21.76	14.28
LD 2.0-4.0	Qu	8,600	2.82	P	7.63	F	+3.97	F	11.01	15.12
LD 6.0-8.0	Jn	10,800	7.88	G	8.27	F	0	-	4.72	12.75
Third seepage investigation, October 15, 1998										
Individual reach										
LD 1.0	Qu	0	0	-	.06		-	-		
LD 1.0-2.0	Qu	5,090	.06	G	2.27		+1.47	F	32.60	13.18
LD 2.0-3.0	Qu	4,970	2.27	F	[1]6.59	GF	+4.06	F	3.95	15.67
LD 3.0-4.0	Qu	3,630	[1]6.59	GF	6.37	F	0	-	-3.34	-13.72
LD 4.0-5.0	Ks	5,940	6.37	F	[1]7.06	FP	0	-	9.77	15.22
LD 5.0-6.0	Jc	3,260	[1]7.06	FP	7.48	F	+.18	P	3.21	15.74
LD 6.0-7.0	Jn	4,630	7.48	F	6.97	F	0	-	-6.82	-15.45
LD 7.0-8.0	Jn	6,170	6.97	F	7.27	F	0	-	4.13	15.67
	TOTAL:	33,690								
Composite reach										
LD 1.0-3.0	Qu	10,060	.06	G	[1]6.59	GF	+5.53	F	15.17	12.74
LD 1.0-4.0	Qu	13,690	.06	G	6.37	F	+5.53	F	12.24	14.97
LD 2.0-4.0	Qu	8,600	2.27	F	6.37	F	+4.06	F	.63	15.93
LD 6.0-8.0	Jn	10,800	7.48	F	7.27	F	0	-	-2.81	-15.78

[1]Average of two or more streamflow measurements at specified site.

downstream contact than at or near the upstream contact. Of those 11 investigations with computed losses, the normalized difference (N_d) was greater than the normalized error (N_e) for 6 investigations. This finding confirms that a source of recharge to the Navajo Sandstone is streamflow losses from streams that originate in the Pine Valley Mountains. Two exceptions to this finding were the October 2 investigation on Leeds Creek when 0.39 ft^3/s more water was measured at the downstream Navajo Sandstone outcrop (LD 8.0) than was measured at the upstream outcrop (LD 6.0), and the October 14 investigation on Wet Sandy Creek when the entire flow was diverted and the reach that traverses the Navajo Sandstone outcrop (W 4.0 to upstream of W 6.0) was dry with no observed inflows. Individual gains were computed between streamflow-measurement sites within some reaches that traverse Navajo Sandstone outcrops, but overall, reaches that traverse the Navajo Sandstone lost water. For example, both the May 12 and October 30 investigations on South Ash Creek show gains at intermediate streamflow-measurement sites S 2.0 or 3.0 within the Navajo Sandstone outcrop. Those gains subsequently were lost in consecutive downstream sites with a net loss of water between the upstream outcrop at S 1.0 and the downstream outcrop of the Navajo Sandstone at S 5.0.

Quaternary Unconsolidated Deposits

Older unconsolidated alluvial-fan and debris-flow deposits of Quaternary age and younger Quaternary-aged unconsolidated deposits are exposed along three creeks: South Ash, Wet Sandy, and Leeds. Contact of the basalt flow and the unconsolidated alluvial deposits along Leap Creek occurs at the confluence with Ash Creek. Older unconsolidated alluvial-fan and debris-flow deposits of Quaternary age are found along the upper reaches of Leeds Creek between LD 1.0 and LD 4.0. Younger Quaternary-aged unconsolidated deposits crop out along the lower reaches of South Ash and Wet Sandy Creeks within the Hurricane Fault zone and overlie bedrock outcrops. No substantial outcrops of the younger Quaternary-aged unconsolidated deposits occur along the lower reach of Leeds Creek.

For all four seepage investigations on South Ash Creek, the reach between S 7.0 and S 10.0 had gains that exceeded the normalized error; however, that interpretation requires clarification. The gains between S 7.0 and S 8.0 resulted from return flow of leakage from the lower Pintura diversion. The reach between S 8.0 and S 10.0 was not influenced by return flows from leaky diversions and showed the seepage characteristics of the unconsolidated deposits. This reach had losses for all four seepage investigations, three of which were greater than normalized error (table 4). Only the loss determined for the May 12, 1998, investigation was less than the normalized error.

Losses were computed for three seepage investigations where Wet Sandy Creek traverses younger Quaternary-aged unconsolidated deposits between W 7.0 and W 9.0. All computed losses have normalized differences that were greater than the normalized error (table 6).

The reach of Leeds Creek between LD 1.0 and LD 4.0 traverses older unconsolidated alluvial and debris-flow deposits. Only one seepage investigation at lower streamflows (October 2, 1998) showed a gain that was greater than the normalized error (table 8). The investigation on May 19, 1998, had incomplete data for the reach between LD 1.0 and LD 4.0, but for the reach between LD 2.0 and LD 4.0, the loss was less than the normalized error.

Igneous Rocks Including Extrusive Basalt Flows and Intrusive Pine Valley Laccolith

Extrusive basalt flows or intrusive Pine Valley laccolithic igneous rocks are exposed along the stream channels of Leap and South Ash Creeks. Wet Sandy and Leeds Creeks have no observed or mapped igneous rocks exposed along the courses studied for seepage losses or gains. In general, for those reaches that have significant natural losses or gains, the losses occur during lower streamflow and the gains, if any, occur at higher streamflows. An intrusive plug of the Pine Valley laccolith is exposed along Leap Creek between LP 4.0 and 5.0. A gain on May 29 and a loss on October 13 were computed for this reach, but neither exceeded the normalized error (table 2).

Leap Creek has carved a box canyon in Quaternary basalt flows between LP 6.0 and LP 8.0. Losses were computed for the entire 9,520-ft reach for all three investigations and range from 0.13 ft^3/s on October 13 to 1.33 ft^3/s during higher streamflows on May 29, although the individual reach between LP 6.0 and LP 7.0 had a gain at higher streamflows (table 2). Normalized differences between LP 6.0 and LP 8.0 ranged from -15.09 to -22.03 percent, and for all three investigations exceeded the normalized error (table 2). Quaternary basalt flows that crop out in the Hurricane Fault zone could provide a pathway for surface water to recharge the ground-water system.

Although a small unmapped basalt flow crops out at S 8.0, the gains between S 7.0 and S 8.0 resulted from return flow of leakage from the lower Pintura diversion and not from natural seepage gain from the basalt outcrop. Because most of this reach consists of outcrops of unconsolidated deposits, it is discussed with Quaternary unconsolidated deposits.

Sedimentary Rocks other than Navajo Sandstone

Sedimentary rocks other than Navajo Sandstone discontinuously crop out along each of the four creeks and include the Carmel Formation, undifferentiated

Cretaceous rocks, and Claron Formation. Short reaches of South Ash and Leeds Creeks flow across outcrops of Carmel Formation. Geologic maps show that the Carmel Formation crops out along Wet Sandy Creek, but its occurrence could not be confirmed. Where South Ash Creek and its tributaries, Mill and Harmon Creeks, flow across the Carmel Formation between S 0.6 and S 1.0 and S 0.8 and S 1.0, only the loss on August 20, 1998, exceeded the normalized difference (table 4). For reaches along Leeds Creek where the Carmel Formation crops out, no significant losses or gains were computed for any of the three seepage investigations.

Undifferentiated Cretaceous rocks crop out along Harmon and Mill Creeks upstream of the upper reaches of South Ash, Wet Sandy, and Leeds Creeks; outcrops along Leap Creek are upstream of the investigated reach. With three exceptions (all on tributaries of South Ash Creek), water was gained in the reaches that traverse the undifferentiated Cretaceous rocks. Gains on Mill (S 0.4 and S 0.6) and Harmon (S 0.2 and S 0.8) Creeks, which join to form South Ash Creek about 200 ft upstream of S 1.0 (table 2), were 0.5 ft^3/s and 0.7 ft^3/s, respectively, on May 12 but did not exceed the normalized error. The same two reaches lost 0.03 ft^3/s and 0.07 ft^3/s on August 20. On October 1, Mill Creek gained 0.32 ft^3/s, and Harmon Creek lost 0.08 ft^3/s, but neither exceeded the normalized error.

Gains computed for the reach between W 1.0 and W 2.0 (or W 3.0) for all three seepage investigations were 0.69 ft^3/s on November 4, 0.72 ft^3/s on October 14, and 1.02 ft^3/s on June 1. All computed gains were greater than the normalized error (fig. 8, table 6). Gains were computed for all three seepage investigations on Leeds Creek where it traverses outcrops of Cretaceous rocks between LD 4.0 to LD 5.0, but none exceeded the normalized error.

Claron Formation crops out along the channels of Leap and South Ash Creeks. In the reaches along Leap Creek where the Claron Formation crops out (LP 3.0 to LP 4.0 and LP 5.0 to LP 6.0), the only large gains or losses were measured between LP 5.0 and LP 6.0. This reach gained 1.12 ft^3/s on May 29, lost 0.12 ft^3/s on October 13, and lost 0.24 ft^3/s on October 29, and all exceeded the normalized error. A reach along South Ash Creek between S 5.0 and S 6.0 where Claron Formation crops out lost 0.14 ft^3/s on August 20, 0.01 ft^3/s on October 30, and gained 0.10 ft^3/s during the October 1 investigation. Neither the two losses nor the one gain were greater than the normalized error.

Specific Conductance and Water Temperature

Specific conductance and water temperature were measured at most streamflow-measurement sites. Specific conductance measures the ability of water to conduct an electrical charge and increases with ion concentration. Rocks composed of soluble minerals generally increase the conductance of water. Specific-conductance values determined at main channel measurement sites ranged from 105 µS/cm at W 1.0 on the upper section of Wet Sandy Creek to 410 µS/cm at LD 1.0 on Leeds Creek. Specific-conductance values in tributary inflows ranged from 77 µS/cm at a tributary inflow of Leeds Creek near Oak Grove Campground to 660 µS/cm at Jones Hollow inflow to Leeds Creek. The specific-conductance value of the tributary inflow from Jones Hollow was at least double the value of Leeds Creek (table 7). One specific-conductance value for Maple Hollow inflow (LP 2.8) on October 29 was 590 µS/cm (table 1), which was higher than the 355 µS/cm measured for Leap Creek. Claron and Carmel Formations crop out in much of the Maple Hollow drainage basin. Higher specific-conductance values generally were measured where water flowed across the Carmel Formation. Although specific-conductance values increased by nearly two- or three-fold along the upper two reaches of Wet Sandy Creek where it traverses the undifferentiated Cretaceous rocks, the downstream values ranged from only 200 to 300 µS/cm. Specific-conductance values were lowest in the spring because of dilution by snowmelt runoff and increase as streamflow approaches base flow. Seasonal variation of specific conductance was smallest for South Ash Creek and largest for Wet Sandy Creek.

Water temperature can indicate the depth of circulation, large geothermal gradients, and geothermal sources of heat. When water temperatures are greater than the local mean annual air temperature and show little or no seasonal variability, a geothermal heat source and (or) deep circulation is suspected. No unusual temperature trends were measured in gaining reaches. Water temperatures measured along all four creeks are low in the spring during snowmelt runoff and increase later in the summer and fall as a result of seasonal and diurnal heating.

SUMMARY

Data were collected from four creeks that drain the eastern flank of the Pine Valley Mountains in Utah, an area with little or no previous hydrologic information, to enhance understanding of the connection between streamflow and the ground-water system and to assist in water-rights and management issues in Dixie National Forest. This report (1) presents streamflow, temperature, and specific-conductance data collected during seepage investigations on Leap, South Ash, Wet Sandy, and Leeds Creeks; (2) computes the amount of loss or gain for specific reaches along each creek; and (3) identifies geologic factors such as rock formations or deposits, faults, and fractures that could influence the amount, timing, and location of seepage losses or gains along the channels of the four drainages.

More than 180 measurements of streamflow or observations of no flow were collected at 53 sites during 13 individual seepage investigations along the 4 creeks (Leap, South Ash, Wet Sandy, and Leeds) in 1998 to determine the amount, timing, and location of streamflow losses (ground-water recharge) or streamflow gains (ground-water discharge). Streamflow was measured at a minimum of eight sites on each of the four creeks during each of three (four on South Ash) seepage investigations at higher streamflows in May and June 1998, and at lower streamflows during August, October, and November 1998. An additional investigation on South Ash Creek was done in August 1998 at the request of the U.S. Forest Service. Only two reaches on Leap and Leeds Creeks showed a significant reversal of loss or gain between high and low streamflows. Streamflow-measurement sites were selected to divide each reach into equal lengths, at rock formation contacts, or immediately above or below inflows or diversions. Tributary inflows and diversion outflows were measured where they occurred.

Rock formation was an influential factor in determining losses and gains, a process that could be enhanced by fractures. No single fault was determined to influence the loss or gain of any reach, however, the influence of faulting in a broader sense could be responsible for the density, distribution, and orientation of fractures that could enhance streamflow losses or gains. A prominent fracture zone in the Navajo Sandstone along South Ash Creek between S 1.0 and S 2.0 was scrutinized, but neither the computed gain at higher streamflows nor the computed losses at lower streamflows were greater than the normalized measurement error.

An error analysis was developed to determine if seepage losses or gains exceed the error associated with measurement of streamflow. The error analysis was computed for individual reaches that used measurement of streamflow at consecutive measurement sites and for composite reaches that used measurement of streamflow at nonconsecutive measurement sites. Determination of losses or gains for composite reaches used only those streamflow measurements made at the upstream- and downstream-most outcrop of a given hydrogeologic unit. Intervening streamflow measurements were not used to compute the error analysis of composite reaches that encompass one of four hydrogeologic units.

To determine if seepage losses or gains were related to geologic features such as rock formation, the loss or gain for each creek where it crosses a specific rock formation was assessed. The four hydrogeologic units assessed were (1) Navajo Sandstone; (2) undifferentiated and unconsolidated Quaternary-age alluvial-fan and debris-flow deposits; (3) igneous rocks that include the intrusive Pine Valley laccolithic rocks of Tertiary age and extrusive basalt flows of Quaternary age; and (4) sedimentary rocks other than the Navajo Sandstone that include Carmel Formation, undifferentiated Cretaceous rocks, and Claron Formation.

Navajo Sandstone crops out along each of the four creeks. For those reaches that traverse outcrops of the Navajo Sandstone, 11 of the 13 seepage investigations measured less water at or near the downstream contact than at or near the upstream contact. Of those 11 investigations with computed losses, the normalized difference (N_d) was greater than the normalized error (N_e) for 6 investigations. This finding confirms that a source of recharge to the Navajo Sandstone is seepage loss from streams that originate in the Pine Valley Mountains.

The reach of Leeds Creek between LD 1.0 and LD 4.0 traverses older unconsolidated alluvial and debris-flow deposits of Quaternary age. One seepage investigation at lower streamflows on October 2, 1998, showed a gain that was greater than the normalized error.

Younger Quaternary-aged unconsolidated deposits are exposed along South Ash Creek between S 7.0 and S 10.0, and Wet Sandy Creek between W 7.0 and W 9.0. Gains greater than the normalized error for all four seepage investigations were found only for the reach between S 7.0 and S 8.0. The gains result from return flow of leakage from the lower Pintura diversion, however, and not from natural accretion of flow. The

reach between S 8.0 and S 10.0 was not influenced by return flow from leaky diversions and was a better example of the seepage characteristics of the unconsolidated deposits. This reach had losses for all four seepage investigations, three of which were greater than normalized error. Losses were computed for three seepage investigations where Wet Sandy Creek traverses younger Quaternary-aged unconsolidated deposits between W 7.0 and W 9.0. All computed losses have normalized differences that were greater than the normalized error.

Igneous rocks that are exposed along Leap Creek include intrusive Pine Valley laccolithic rocks of Tertiary age between LP 4.0 and LP 5.0, and extrusive basalt flows of Quaternary-age extrusive basalt flow between LP 6.0 and LP 8.0. A loss and a gain were computed for the reach that traverses the intrusive rocks, but neither exceeded the normalized difference. The reach that traverses the basalt flows between LP 6.0 to LP 8.0 lost water for all three seepage investigations and the normalized differences exceeded the normalized error. A small unmapped basalt flow along South Ash Creek occurs at site S 8.0; however, the outcrop is of such limited extent that the reach between S 7.0 and S 10.0 was analyzed with the younger unconsolidated deposits hydrogeologic unit.

Sedimentary rocks other than Navajo Sandstone discontinuously crop out along each of the four creeks and include the Carmel Formation, undifferentiated Cretaceous rocks, and Claron Formation. Short reaches of South Ash and Leeds Creeks flow across outcrops of Carmel Formation. Where Mill and Harmon Creeks (both tributaries of South Ash Creek) flow across the Carmel Formation between S 0.6 and S 0.8, and S 1.0, only one loss on August 20, 1998, exceeded the normalized difference. Geologic maps show that the Carmel Formation crops out along Wet Sandy Creek, but this could not be confirmed. Along Leeds Creek where the Carmel Formation crops out, no significant losses or gains were computed for any of the three seepage investigations.

Undifferentiated Cretaceous rocks crop out along the upper reaches of South Ash, Wet Sandy, and Leeds Creeks; outcrops along Leap Creek are upstream of the investigated reach. Only one gain on Mill Creek, a tributary of South Ash Creek, exceeded the normalized difference. Gains on Wet Sandy Creek between W 1.0 and W 2.0 (or W 3.0) exceeded the normalized differences for all three seepage investigations.

Claron Formation crops out along the channels of Leap and South Ash Creeks. In the reaches along Leap Creek where the Claron Formation crops out (LP 3.0 to LP 4.0 and LP 5.0 to LP 6.0), only the gain on May 29 and both losses on October 13 and 29, 1998, between LP 5.0 and LP 6.0, exceeded the normalized error.

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