

Delineation of Recharge Areas for Karst Springs in Logan Canyon, Bear River Range, Northern Utah

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Abstract

Fluorescent-dye tracing was used to determine recharge areas, general directions of ground-water flow, and residence times for water from four karst springs in the Logan Canyon area of the Bear River Range in northern Utah. Dewitt, Wood Camp Hollow, Logan Cave, and Ricks Springs discharge from Paleozoic-age carbonate rocks into the Logan River, which is base level for ground water that discharges from this alpine region.

Recharge to the carbonate aquifer occurs through point sources, as seepage losses through fluvio-glacial deposits, and as diffuse infiltration. On the basis of dye tracing to date (1999), recharge areas for Dewitt, Wood Camp Hollow, and Ricks Springs are estimated to be between 7.5 and 15 square miles and as much as 3,200 feet higher than the altitude of the springs. Results of dye tracing indicate maximum ground-water travel times of 8 to 31 days from losing streams as far as 7.2 miles. Dye tracing also indicates that surface-water drainage basins generally do not coincide with ground-water basins. Ground-water movement in a large part of the area is influenced by the Logan Peak syncline.

Discharge of springs ranges from less than 1 to about 75 cubic feet per second. Spring discharge responds primarily to snowmelt runoff, with peak flow from late spring to early summer and base flow during the winter months. Specific conductance of spring water from May 1994 to July 1997 ranged from 250 to 420 microsiemens per centimeter at 25 degrees Celsius and water temperature ranged from 5.5 to 8.0 degrees Celsius. For all springs, specific conductance and temperature were inversely related to discharge. Observed differences between measured values result primarily from mixing of recharge derived from snowmelt with ground water.

INTRODUCTION

The Bear River Range in northern Utah and southern Idaho is part of the Middle Rocky Mountains Physiographic Province (Stokes, 1988). The range is part of a thrust sheet (allochthon) that was emplaced eastward by a deeply buried thrust fault during Cretaceous time (Dover, 1987). In northern Utah, the range is bisected by several east to west rivers, including the Logan River (fig. 1). In the Logan Canyon area, east of Logan, Utah, altitude ranges from about 5,000 feet (ft) along the river to almost 10,000 ft on higher peaks. Mean annual precipitation at Tony Grove Lake (8,000 ft) for 1979-99 was 49.8 inches (Natural Resources Conservation Service SNOTEL data, <http://utdmp.utsnow.nrcs.usda.gov>). Most precipitation occurs as snow from October to March.

Karst features in the Logan Canyon area are indicative of a hydrologic system that is developed within more than 3,000 ft of Paleozoic limestone and dolomite. Karst features in this alpine region include large springs that discharge along major rivers, losing streams in tributary drainages, caves and pits, blind valleys, sinkholes, dolomite pavement, and surficial karst (karren). Glaciation occurred above 8,000 ft

during the Pleistocene, resulting in destruction of karst landforms that developed during interglacial periods (Wilson, 1976). Speleothem age-dating, fluvio-glacial deposits in caves, and deranged topography indicate that existing karst features, particularly caves, are largely remnants of former karst landscapes.

Karst systems in alpine terrains are substantially different from those in relatively flat-lying strata in more temperate regions. Characteristics of alpine karst systems include a large component of vertical solution development and a thick unsaturated (vadose) zone, steep hydraulic gradients, spring discharge that responds primarily to snowmelt runoff, pit development in high-altitude meadows, and cold-temperature dissolution of carbonate rocks. To better characterize the hydrologic system in this alpine karst, an investigation was begun to (1) determine variations in discharge of selected large springs; (2) correlate temperature and specific conductance of spring water with changes in discharge; (3) determine recharge areas for the springs and general directions of ground-water flow; (4) delineate ground-water basin divides; (5) determine ground-water travel times; and (6) evaluate the effects of geology on ground-water movement.

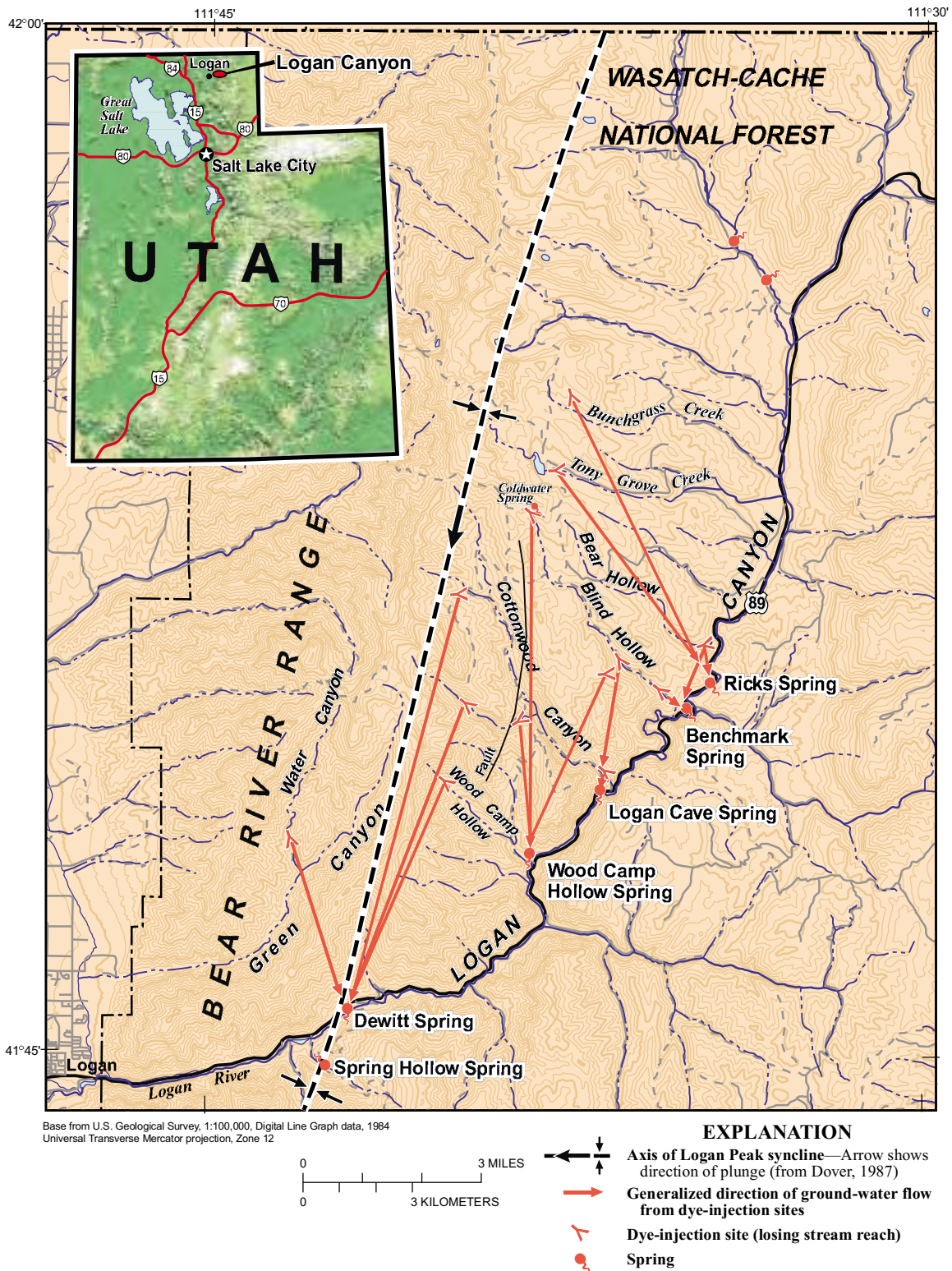


Figure 1. Generalized ground-water flow paths to selected springs, on the basis of results of dye tracing, Logan Canyon, Utah.

METHODS

Dye-tracing methods commonly are used to determine ground-water flow paths, relations between surface-water and ground-water basins, and ground-water travel times in karst aquifers (Mull and others, 1988). Dye tracers have been successfully used in karst and other high-permeability terrains where other types of tracers have limited use. Sodium fluorescein dye was selected as the principal tracer for this investigation. Characteristics of the dye include detectability at low concentrations and over long distances, relatively low sorption tendencies, good solubility in cold water, low cost, and an affinity for activated charcoal. Dye tracing was done during low to moderate spring flows and dye amounts were based on discharge and distance from the springs. In place of automatic water samplers, passive (cumulative) dye detection with activated charcoal was used to recover the dye for analysis. Dye packets were exchanged every 1 to 4 weeks; consequently, calculated ground-water travel times are considered maximums and in most cases, are probably substantially less. Procedures for recovery of dye from activated charcoal are outlined in Mull and others (1988).

Discharge from most springs in the study area is not gaged. Spring discharge was measured periodically at different flow rates with a pygmy current meter, and intervening flow rates were estimated. Small spring flows were measured with a modified Parshall flume. Discharge at peak flows is estimated to be within plus or minus 20 percent of actual values. Discharge data for Dewitt Spring were obtained from the City of Logan Water Department (Dennis Corbridge, written commun., 1998). Specific conductance was measured with a Beckman conductivity meter that was periodically calibrated to known standards. Water temperature was measured to the nearest one-half degree with a mercury thermometer.

HYDROGEOLOGY

The Bear River Range consists in large part, of a thick sequence of carbonate (limestone and dolomite) rocks that range in age from Cambrian to Mississippian (Dover, 1987). The principal geologic units in this area and approximate thicknesses are the Garden City Formation (1,400 to 2,000 ft), Swan Peak Quartzite (200 to 400 ft), and Fish Haven Dolomite (350 ft) of Ordovician age; the Laketown Dolomite (1,500 to 2,000 ft) of Silurian age; the Water Canyon Formation (425 to 600 ft), Hyrum Dolomite (850 ft), and Beirdneau Formation (1,000 ft) of Devonian age; and the Lodgepole Limestone (750 ft) of Mississippian age. Karst is more developed in the Garden City Formation and Laketown Dolomite than in the other carbonate units. All of the units, however, are capable of transmitting water along dissolution-enhanced

fractures, faults, and bedding planes. The Swan Peak Quartzite is probably a barrier to downward movement of water from the Fish Haven Dolomite to the Garden City Formation in some areas and likely influences the direction of ground-water movement. All of the formations make up the upper part of a large regional structure, the Logan Peak syncline (Williams, 1948) (fig. 1). The syncline plunges to the southwest at about 15 degrees and rocks on the west limb dip at a considerably steeper angle than those on the east limb. This structural feature and associated fractures influence the movement of ground water in much of the region.

Aquifer Recharge

Recharge to the carbonate aquifer takes place through point sources (sinkholes and pits), as seepage losses through fluvio-glacial deposits that fill valley drainages, and as infiltration along ridges and valley slopes. Sinkholes (dolines) and pits are typically developed in high-altitude meadows where snow accumulates and may persist throughout much of the year. Water entering point sources moves vertically downward along solution-enlarged fractures to principal conduits that channel water to the springs. Pits range in depth from less than 100 to as much as 300 ft, but many of these have been occluded by fluvio-glacial materials consisting primarily of quartzite boulders. Fluvio-glacial deposits also form a veneer over carbonate bedrock in valley drainages. These deposits are very permeable and streams typically sink into the streambed along distances of several hundred yards rather than in distinct point sources such as swallow holes. These losing reaches are probably related to fracture zones within the underlying bedrock. Most streams in these alpine drainages are fed by snowmelt runoff and, therefore, tend to be seasonal. During periods of peak runoff, however, streamflow that is not lost to the underlying bedrock continues down surface-water courses to the Logan River. Infiltration of snowmelt along ridges and valley slopes provides an additional component of recharge to the aquifer and probably moves along diffuse pathways through the fractured-rock matrix. Diffuse flow can be a significant component of long-term storage in the aquifer and maintenance of base flow of springs.

Discharge from Springs

Discharge from the carbonate aquifer is primarily from large springs along the Logan River. The Logan River is the principal base level stream for ground-water discharge in this part of the Bear River Range. Three second magnitude (average discharge between 10 and 100 cubic feet per second (ft³/s)) and two third magnitude (average discharge between 1 and 10 ft³/s) springs, along with several smaller springs, discharge

along the north and west sides of the river (fig. 1). These include Dewitt, Wood Camp Hollow, Logan Cave, and Ricks Springs. Only one large (second magnitude) spring is known to discharge along the south side of the river (fig. 1). Collective discharge of the springs provides a substantial component of streamflow in the Logan River. Wilson (1976) estimated that the combined flow of Wood Camp Hollow, Logan Cave, and Ricks Springs could be as much as 20 percent of the discharge of the Logan River. Spring discharge responds primarily to snowmelt runoff, with peak flow from late spring to early summer and base flow during the winter months (fig. 2).

Dewitt Spring discharges from the Water Canyon Formation along the flood plain of the Logan River (fig. 1). Water discharges from an unknown number of outlets that are capped and is diverted into a collection system. Water from the spring serves as a public supply for the city of Logan, about 7 miles (mi) to the west. Discharge of the spring is metered and generally ranges from about 10 to 35 ft³/s (Dennis Corbridge, City of Logan, written commun., 1998) (fig. 2).

Wood Camp Hollow Spring discharges from two adjacent outlets in the Laketown Dolomite. Discharge of the spring ranges from about 3 to at least 40 ft³/s. Discharge at peak flow is difficult to determine because backwater from the Logan River partially impounds free flow from the spring. During base flow, discharge

from both outlets appears to be similar. As discharge increases, however, substantially greater amounts of water discharge from the upstream outlet, and flow from the adjacent (downstream) outlet is estimated to be less than 10 ft³/s.

Logan Cave Spring discharges from the base of the Garden City Formation. Water from the spring normally discharges from talus below the entrance to Logan Cave, but during spring runoff, also discharges directly from the cave entrance. Discharge of the spring normally ranges between 1 and 10 ft³/s; Wilson (1976) estimated flows of as much as 25 ft³/s in June 1975. Peak flow of Logan Cave Spring generally occurs earlier than that of the other springs. Most of Logan Cave is developed along a master joint that trends due north, with dissolution along secondary northwest-trending joints in some areas.

Ricks Spring discharges from four outlets along several hundred yards of a normal fault in the Garden City Formation. Discharge of the spring ranges from less than 1 to a reported 75 ft³/s (Mundorff, 1971). During snowmelt runoff, most water discharges from a large alcove developed on the fault, and estimated combined flow from the three additional outlets is less than 5 ft³/s. During winter, flow generally ceases from the alcove, and total base flow from the smaller springs, which are at a slightly lower altitude along the Logan River, can be less than 1 ft³/s.

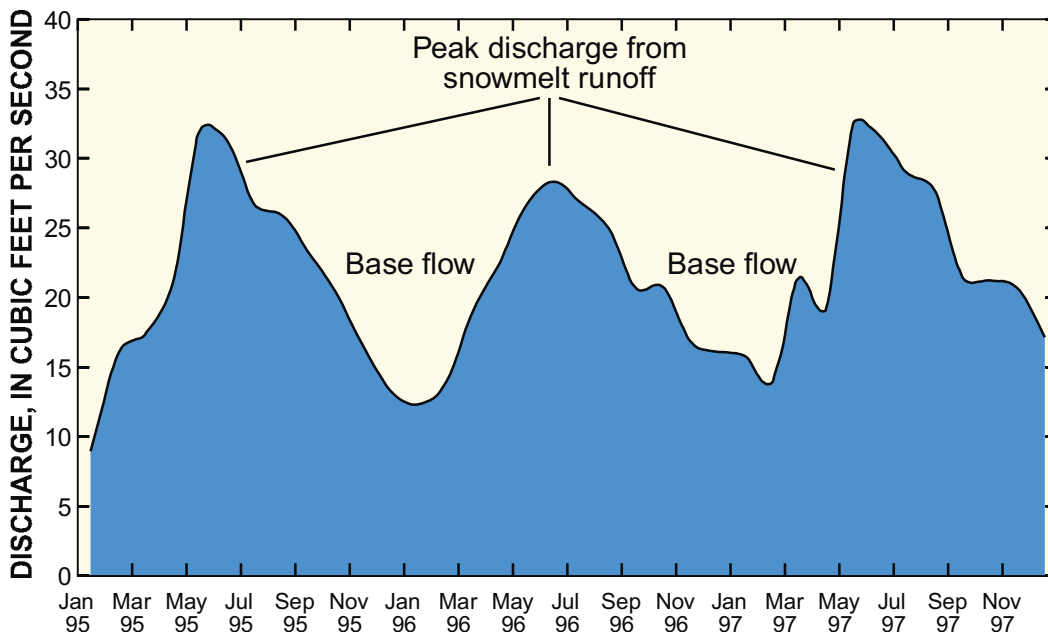


Figure 2. Hydrograph showing typical seasonal response of an alpine karst spring to snowmelt runoff, Dewitt Spring, Logan Canyon, Utah, January 1995 to January 1998 (Data from City of Logan Water Department, written commun., 1998).

RESULTS OF DYE TRACING

Results of dye tracing indicate that water from losing streams moves downward through fluvio-glacial deposits into underlying carbonate rocks to discharge areas along the Logan River. In some areas, water moves vertically downward through more than one carbonate unit before discharging. Dye tracing also indicates that surface-water drainage basins do not necessarily coincide with ground-water basins. Water from losing streams typically moves beneath ridges from one surface-water basin to discharge areas in adjacent surface-water basins. Furthermore, streams in the upstream and downstream parts of some drainages lose water to different ground-water basins. Streams in the Cottonwood Canyon surface-water basin lose water to three separate ground-water basins (fig. 1). Interbasinal ground-water movement between springs during periods of high flow has been documented in alpine karst areas of eastern Utah (Maxwell and others, 1971). Although this phenomenon has not been observed in this area on the basis of dye tracing at low to moderate flows, ground-water basin divides can be dynamic boundaries, particularly where these divides cross stream drainages.

Four dye traces to Dewitt Spring indicate a recharge area northwest to northeast of the spring that largely coincides with the areal extent of the Logan Peak syncline. Ground-water movement is probably downdip along the west and east limbs of the syncline toward the axis (fig. 1), and subsequently southwest to the spring, which is located along the axis of the syncline where the Logan River breaches the structure. Results of dye tracing during moderate flow indicate a maximum ground-water travel time of 22 days for losing streams in drainages 7.2 mi from, and 2,900 ft higher than, Dewitt Spring (table 1). The substantial base flow of this spring relative to peak flow may indicate a large storage component that is recharged primarily from infiltration. Ground-water travel times from this diffuse component of flow are likely to be considerably longer than those from losing streams. On the basis of dye tracing, geology, and discharge, the ground-water basin for Dewitt Spring is estimated to be about 15 square miles (mi²).

Three dye traces to Wood Camp Hollow Spring indicate a recharge area generally north of the spring and as much as 3,200 ft higher than the spring. Results of dye tracing during moderate flow also indicate a maximum ground-water travel time of 28 days to the spring from as far as 5.6 mi (table 1). Ground-water

movement within the Wood Camp Hollow Basin is probably along north-trending fractures and possibly faults (fig. 1). Southwest-dipping strata along the east limb of the Logan Peak syncline, however, may influence ground-water movement from the northeast. In-cave tracing from this area indicates largely vertical movement of water for almost 1,000 ft. Water then probably moves downdip to the southwest, possibly along the top of the Swan Peak Quartzite, to where it eventually merges with flow in the principal conduit. On the basis of dye tracing, discharge, and relations to adjacent ground-water basins, the recharge area for Wood Camp Hollow Spring may be as large as 10 mi².

Two dye traces to Logan Cave Spring indicate a recharge area generally north of the spring and at a lower altitude than that of the recharge areas for the other springs (fig. 1). Substantial contributions to discharge of this spring originate from the lower part of Cottonwood Canyon and the Blind Hollow drainage (fig. 1). Movement of ground water to this spring is probably largely within the Garden City Formation. Dye tracing, discharge, and relations to adjacent ground-water basins indicate that the recharge area for Logan Cave Spring is probably less than 5 mi².

Three dye traces to Ricks Spring indicate a recharge area that extends more than 5 mi to the northwest and about 2,600 ft higher than the spring (fig. 1). Water that originates from the lower part of Bear Hollow also appears to move laterally along the fault on which the spring is located, to discharge at Benchmark Spring, about half a mile to the southwest (fig. 1). In addition, investigations by the U.S. Forest Service during the 1970s (District Ranger, Wasatch-Cache National Forest, oral commun., 1999) indicate that part of the flow to Ricks Spring originates directly from the Logan River. Losses from the Logan River are probably along an extension of the fault where it intersects the river upstream from the spring. Maximum travel time of ground water to the spring from 5.3 mi during low flow was 28 days (table 1). Ground-water movement in the Ricks Spring Basin appears to be generally along the east limb of the Logan Peak syncline and probably within the Garden City Formation. Northwest-trending high-angle faults are mapped northeast of the Ricks Spring ground-water basin, on the east side of the Logan River; however, younger deposits mantle the carbonate rocks in the basin and obscure structural relations. On the basis of dye tracing, the recharge area for Ricks Spring is estimated to be at least 7.5 mi².

Table 1. Summary of dye traces to selected karst springs in Logan Canyon, Utah

[—, no data; <, less than]

Maximum travel time: Travel time calculated from initial dye recovery on activated charcoal; actual travel time probably substantially less.

Linear distance: Straight-line distance between dye-input and dye-recovery sites; actual distance probably substantially greater.

Vertical distance: Difference between altitudes of dye-input and dye-recovery sites.

Spring discharge: Estimated/measured discharge of spring at time of dye injection.

Dye-input site	Altitude (feet)	Date and time of dye injection	Amount of fluor-escetin dye (pounds)	Dye-recovery site	Altitude (feet)	Date and time of dye recovery	Maximum travel time (days)	Linear distance (miles)	Vertical distance (feet)	Spring discharge (cubic feet per second)
Dewitt Spring Basin										
South Fork, Cottonwood Canyon	7,160	09/15/1995	2.4	Dewitt Spring	5,040	10/09/1995	1745	5.6	2,120	25
Upper Wood Camp Hollow	7,120	09/13/1996	2.0	Dewitt Spring	5,040	10/14/1996	1415	4.3	2,080	23
Upper Cottonwood Canyon	7,920	07/05/1998	4.4	Dewitt Spring	5,040	07/27/1998	1740	7.2	2,880	28
Water Canyon	6,320	11/11/1999	2.0	Dewitt Spring	5,040	11/19/1999	1500	3.0	1,280	20
Wood Camp Hollow Basin										
South Fork, Cottonwood Canyon	6,460	09/21/1991	1.6	Wood Camp Hollow Spring	5,360	10/12/1991	1230	2.3	1,100	5
Coldwater Spring	8,520	09/11/1993	3.4	Wood Camp Hollow Spring	5,360	10/09/1993	1640	5.6	3,160	12
Nielsens Cave	17,000	09/10/1994	—	Wood Camp Hollow Spring	5,360	09/30/1994	1505	3.3	1,640	11
Logan Cave Spring Basin										
Blind Hollow	6,800	11/11/1993	1.3	Logan Cave Spring	5,520	12/04/1993	1545	2.3	1,280	1
Cottonwood Canyon	5,640	10/14/1996	1.0	Logan Cave Spring	5,520	11/11/1996	1345	.30	120	1
Ricks Spring Basin										
Bear Hollow	6,120	10/12/1991	.72	Ricks Spring	5,880	10/26/1991	1550	.68	240	4.5
Bear Hollow	6,120	11/11/1992	1.1	Ricks Spring	5,880	11/28/1992	1450	.68	240	2
				Benchmark Spring	5,800	11/28/1992	1420	1.0	320	<1
Blind Hollow	6,200	04/26/1992	.83	Benchmark Spring	5,800	05/16/1992	1915	.80	400	1
Tony Grove Creek	7,980	06/07/1992	3.4	Ricks Spring	5,880	07/02/1992	1940	4.3	2,100	10
Bunchgrass Creek	8,520	08/13/1994	3.6	Ricks Spring	5,880	09/10/1994	1650	5.3	2,640	7.5

¹ Approximate altitude of dye-injection site inside cave.

PHYSICAL PROPERTIES OF SPRING WATER

Water temperature and specific conductance were measured at Wood Camp Hollow, Logan Cave, and Ricks Springs from May 1994 to July 1997, along with estimates of discharge. For all springs, specific conductance and temperature of water were inversely related to discharge. During periods of runoff and peak flow (late spring to early summer), specific conductance of water from the springs ranged from 250 to 290 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) at 25 degrees Celsius ($^{\circ}\text{C}$) and temperature ranged from 5.5 to 6.0 $^{\circ}\text{C}$ (fig. 3). Conversely, during periods of base flow (late fall to late winter), specific conductance of water ranged from 340 to 420 $\mu\text{S}/\text{cm}$ and temperature ranged from 6.5 to 8.0 $^{\circ}\text{C}$ (fig. 3). Observed differences between measured values result from mixing of recharge derived from snowmelt with ground water. Snowmelt (low dissolved-solids concentration) from point sources and losing streams moves rapidly through the aquifer along dissolution-enhanced flow paths (joints, faults, and bedding planes), mixing with ground water in storage (higher dissolved-solids concentration) that has had a longer residence time. McGreevy and Bjorklund (1970) reported specific-conductance values of water from Ricks Spring that averaged 341 $\mu\text{S}/\text{cm}$ for periods of base flow between 1958 and 1962. This average value is virtually identical to values obtained during this investigation and indicates that the dissolved-solids concentration in water from this spring has probably remained essentially the same for at least 40 years.

Hydrogen-ion activity (pH) was not measured during this investigation. However, Wilson (1976) reported monthly pH values of 7.4 to 7.7 for Wood Camp Hollow, Logan Cave, and Ricks Springs. McGreevy and Bjorklund (1970) also reported pH values of 7.4 to 8.2 for Ricks Spring and values of 8.0 and 8.1 for Dewitt Spring. Reported values of pH and corresponding estimated discharge do not indicate a definitive relation between these parameters.

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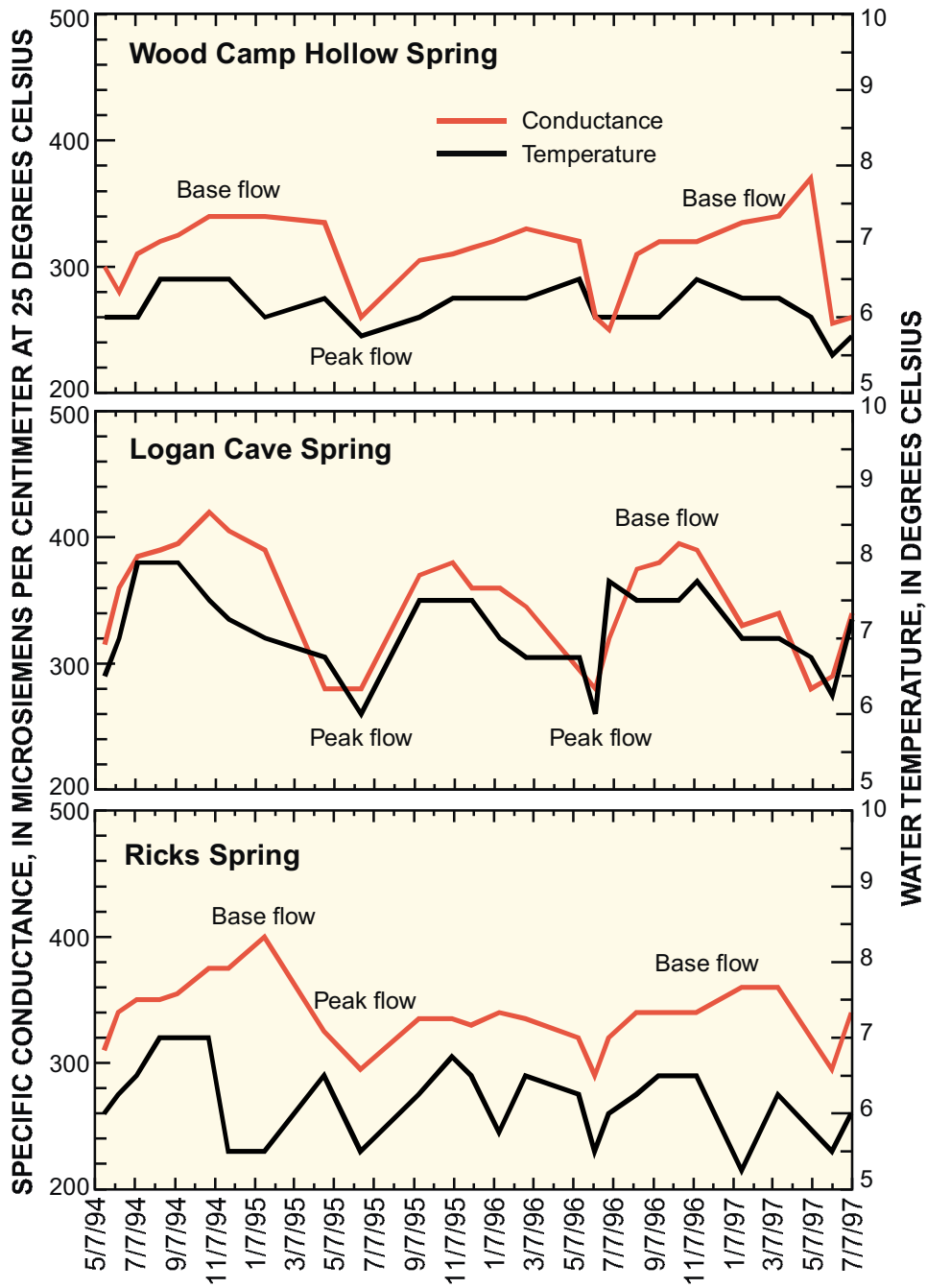


Figure 3. Relation of specific conductance and water temperature to peak and base flows of selected springs, Logan Canyon, Utah, May 1994 to July 1997.