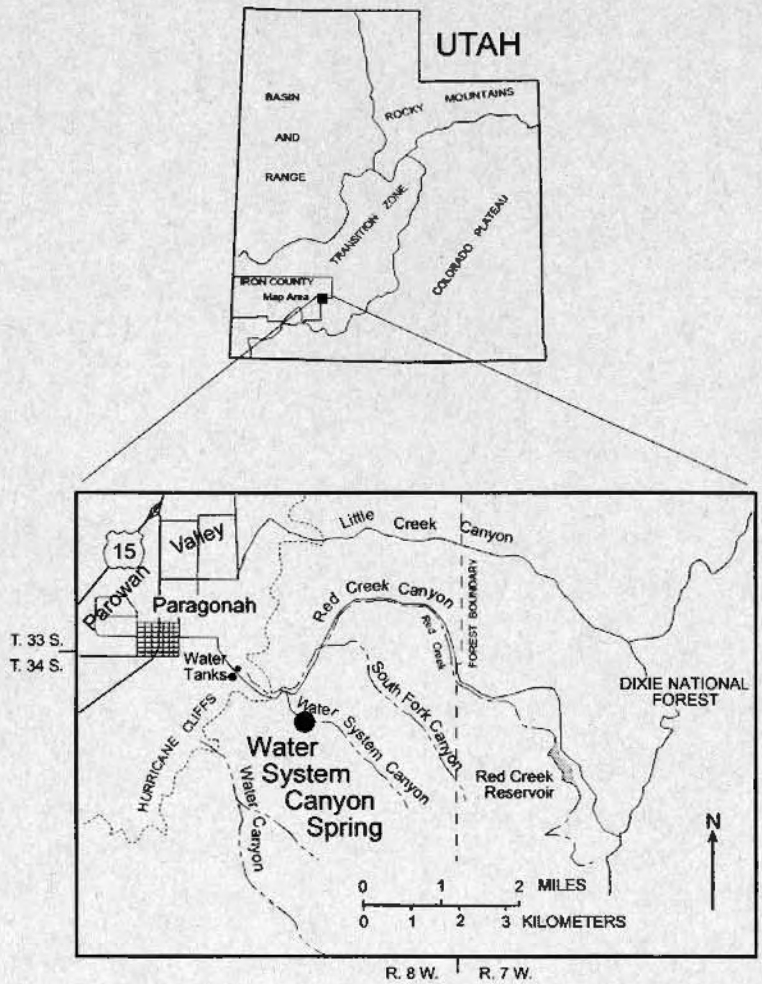
DELINEATION OF DRINKING WATER SOURCE PROTECTION ZONES FOR WATER SYSTEM CANYON SPRING, A PUBLIC WATER SUPPLY SPRING, IRON COUNTY, UTAH

by
Charles E. Bishop



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ABSTRACT

This study delineates drinking-water-source-protection zones for Water System Canyon Spring, which is used by the Paragonah Municipal Water System as a source of drinking water for the town of Paragonah. The spring is in Water System Canyon, a tributary to Red Creek Canyon on the western edge of the Markagunt Plateau, eastern Iron County. Red Creek is a substantial perennial stream draining the plateau. The climate of the area is semiarid to humid and average annual precipitation is about 14 inches (35.5 cm); however, up to 35 inches (89 cm) can be received in the higher mountains.

The stratigraphy of the Markagunt Plateau is characterized by a succession of exposed Cenozoic volcanic, volcaniclastic, and sedimentary rocks underlain in the subsurface by Cretaceous, Jurassic, and older sedimentary rocks. Extrusive lava flows of Tertiary and Quaternary age mantle large tracts of land, and small igneous dikes and plugs are found throughout the area. The sedimentary rocks near Water System Canyon Spring typically dip toward the north and northwest, away from the high mountainous areas, but faults interrupt the regional dip of the rocks. The dominant structures in the area are northeast-trending grabens and half grabens. Fault systems generally have an associated extensive network of fractures.

Springs in the Red Creek Canyon area are excellent sources of water, flowing up to several hundred gallons per minute. High-yielding springs are commonly located along the major fault systems of the area. Fault/fracture systems, along with some bedding planes and lithologic contacts, provide preferential pathways for ground-water flow and profoundly affect the regional ground-water flow patterns of the area. Precipitation in topographically high outcrop areas is ultimately the source of most recharge to the springs.

Water System Canyon Spring issues from colluvial and alluvial gravel deposits on the southwest side and bottom of Water System Canyon. The spring developed when the drainage downcut through confining strata at a fault/fracture intersection. Chemical constituents in Water System Canyon Spring water are derived principally from the dissolution of carbonate minerals from sedimentary rocks, and siliceous minerals from sedimentary and volcanic rocks. A hydrologic budget of the Red Creek Canyon catchment area indicates more water leaves the watershed than enters. This indicates the presence of a more regional aquifer, larger than the Red Creek Canyon catchment area. A catchment area of about 3.5 square miles (9 km^2) would be necessary to provide enough water to

account for the flow from Water System Canyon Spring based on average annual precipitation and evapotranspiration rates in the area. Thus, some ground-water discharge from Water System Canyon Spring is probably from a more regional aquifer, which is at relatively shallow depths in this area.

A "Preferred Delineation Procedure" was used to delineate protection zones around Water System Canyon Spring. Analysis of the geology and hydrogeology of the area indicates that the spring is along one of the regional fault/fracture systems. Other regional fault/fracture systems also supply water to springs in the area and thus limit the areas contributing ground water to Water System Canyon Spring. A volumetric method was used to calculate the volume of the aquifer needed to supply enough water for a given time period to the spring. The volumetric method was conservative in not accounting for: (1) the recharge within the spring's zone of contribution, and (2) water from a more regional aquifer feeding the spring. Drinking-water-source-protection zones 2, 3, and 4 for the spring are delineated based on the combined results of the hydrogeologic investigation, volumetric calculations, and the topography of the area. All zones are topographically upgradient of the spring. To be conservative (protective), the boundaries of all three DWSP zones extend south of the spring and exceed the calculated time-of-travel distance using the volumetric method. The boundaries extend toward the higher elevations and take into account the fault/fracture system trend. The maximum upgradient distance from the spring to DWSP-zone 4 boundary is about 5,800 feet (1,768 m) and zone 3 was combined with zone 4 because of the uncertainties in the aquifer system. These zones overlap another fault/fracture system that also has an associated spring; water falling in this area is probably not contributing to Water System Canyon Spring, but this area was included in the delineated zones to be conservative. The zone 2 boundary is placed 1,366 feet (416 m) upgradient from the spring.

INTRODUCTION

This report describes the delineation of drinking-water-source-protection (DWSP) zones for a public-water-supply spring (Utah Division of Drinking Water system number 11014, source number 02) in the SE¼ NE¼ NE¼ section 36, T. 34 S., R. 8 W., Salt Lake Base Line and Meridian (SLBM), eastern Iron County, Utah (figure 1). Water System Canyon Spring is about 2 miles (3 km) east of the town of Paragonah, within the Markagunt Plateau. Much of the surrounding area is privately owned and used f cattle grazing The town of Paragonah is a rural farming community that obtains part of

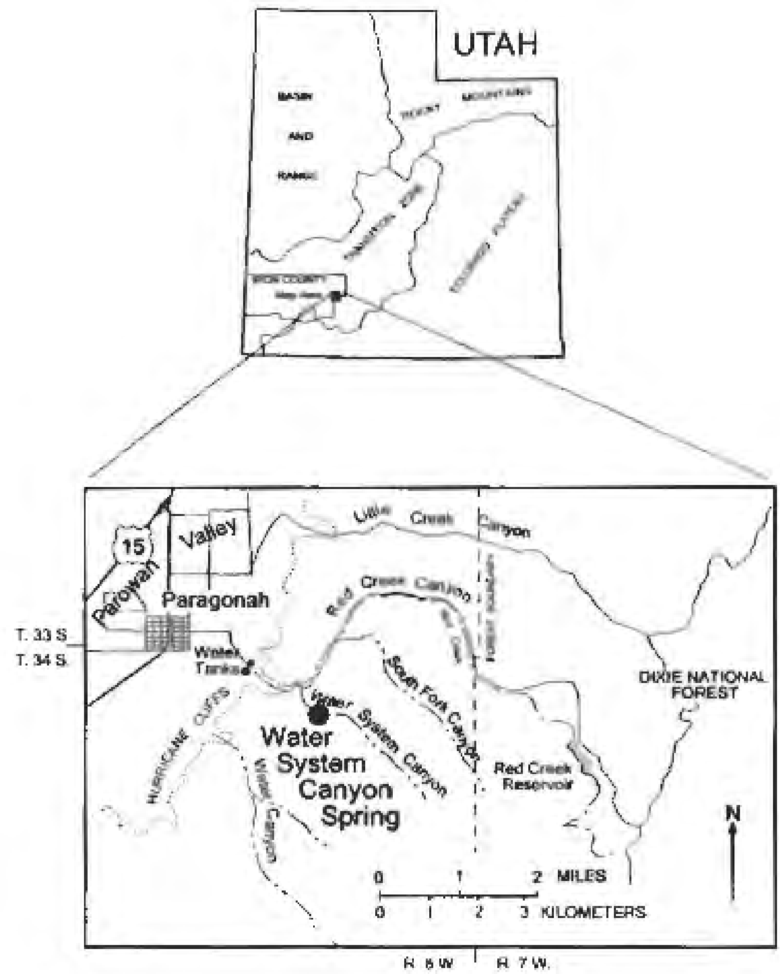


Figure 1. Location of Water System Canyon Spring. Index map of Utah shows physiographic provinces.

its municipal drinking water from this spring, and requested this delineation of DWSP zones. The scope of work included a literature search, review of water records, field reconnaissance, interpretation of data, delineation of the DWSP zones, and preparation of this report.

Utah's Drinking Water Source Protection Rule (R309-113, Utah Administrative Code; administered by the Utah Division of Drinking Water) requires public-water suppliers in Utah to develop a DWSP plan for each well or spring used as a public-drinking-water source. The delineation of DWSP zones around public-water supplies is a major component of the DWSP plan.

The delineation of DWSP zones is part of a preventive strategy to minimize potential degradation of water quality by defining areas that provide water to wells and springs over specific time intervals. This strategy creates a limited area to concentrate resources for inventory, control, and monitoring with an overall goal of assuring the quality of public-water supplies. Local governments can then implement land-use regulations to protect and reduce the risk of future ground-water contamination and costly remediation efforts in these areas. Utah's DWSP Rule (R309-113-9 [1]) defines four DWSP zones:

Zone 1 - the area within a 100-foot (30-m) radius from the spring collection area;

Zone 2 - the area within a 250-day ground-water time of travel to the spring collection area, the boundary of the aquifer(s) that supplies water to the spring, or the ground-water divide, whichever is closer to the spring;

Zone 3 - (waiver zone) - the area within a 3-year ground-water time of travel to the spring collection area, the boundary of the aquifer(s) that supplies water to the spring, or the ground-water divide, whichever is closer to the spring; and

Zone 4 - the area within a 15-year ground-water time of travel to the spring collection area, the boundary of the aquifer(s) that supplies water to the spring, or the ground-water divide, whichever is closer to the spring.

The DWSP Rules require the delineation of zones 1, 2, and 4. A waiver zone, zone 3, is included to help the water supplier with future monitoring waivers (see R309-1104).

To delineate DWSP zones one of two procedures may be used: (1) a "Preferred Delineation Procedure," based on ground-water times of travel and local geology and hydrogeology, or (2) an "Optional Two-Mile Radius Delineation Procedure," based on identifying all upgradient areas supplying water to a well or spring within a fixed 2-mile (3.2 km) radius of the drinking-water source. I delineated the DWSP zones for Water System Canyon Spring using the "Preferred Delineation

Procedure" because it reflects the hydrogeologic system and I believe it to be more accurate than the other procedure.

In this study, I delineated DWSP zones 2, 3, and 4. Zone 1, a 100-foot (30 m) fixed radius around the spring, is not shown on the map or discussed further in this report.

GEOLOGY

Water System Canyon Spring is in Water System Canyon, on the western edge of the Markagunt Plateau, about 1 mile (1.6 km) east of the Paragonah fault, which forms the eastern boundary of the Markagunt Plateau (Anderson and Christenson, 1989). The Markagunt Plateau, the southwesternmost of the High Plateaus of Utah, is flanked on the west by Parowan Valley and on the east by Sevier Valley. This area is part of the transition zone between the Basin and Range and the Colorado Plateau physiographic provinces (Stokes, 1977). The block-faulted nature of the transition zone resembles that of the Basin and Range, but the high elevation and relief are more like the Colorado Plateau. The Markagunt Plateau is characterized by a series of narrow, steep, westward sloping, alluvial-bottom canyons; mesas and buttes; elongated, closed valleys with aligned drainages; gullies; depressions; and aligned volcanic cones (Anderson and Christenson, 1989). The Markagunt Plateau has been subjected to considerable erosion, and has been remodeled by volcanism and minor glaciation over the last 30,000 years.

The Markagunt Plateau contains carbonate-dominated Paleozoic rocks, clastic-dominated Mesozoic rocks, and clastic- and volcaniclastic-dominated Cenozoic rocks (figures 2 and 3). Only Tertiary and younger rocks are exposed in the area, but Mesozoic and Paleozoic strata are present in the subsurface and exposed in adjoining areas. Jurassic rocks include sandstones of the Navajo Sandstone and Temple Cap Formation equivalent, and the Carmel Formation, composed of limestone, sandstone, mudstone, siltstone, and gypsum. Cretaceous rocks in the area are the Iron Springs Formation which is composed of sandstone, siltstone, shale, and conglomerate. Exposed Tertiary strata include the Grand Castle, Claron, and Brian Head Formations. These sedimentary strata are composed of sandstone, tuffaceous sandstone, conglomerate, mudstone, siltstone, claystone, mudflow breccia, pebble-boulder conglomerate, and limestone. The Claron Formation is a colorful sequence of red, orange, gray, and white fluvial and lacustrine strata most spectacularly exposed at Bryce Canyon (Anderson, 1987).

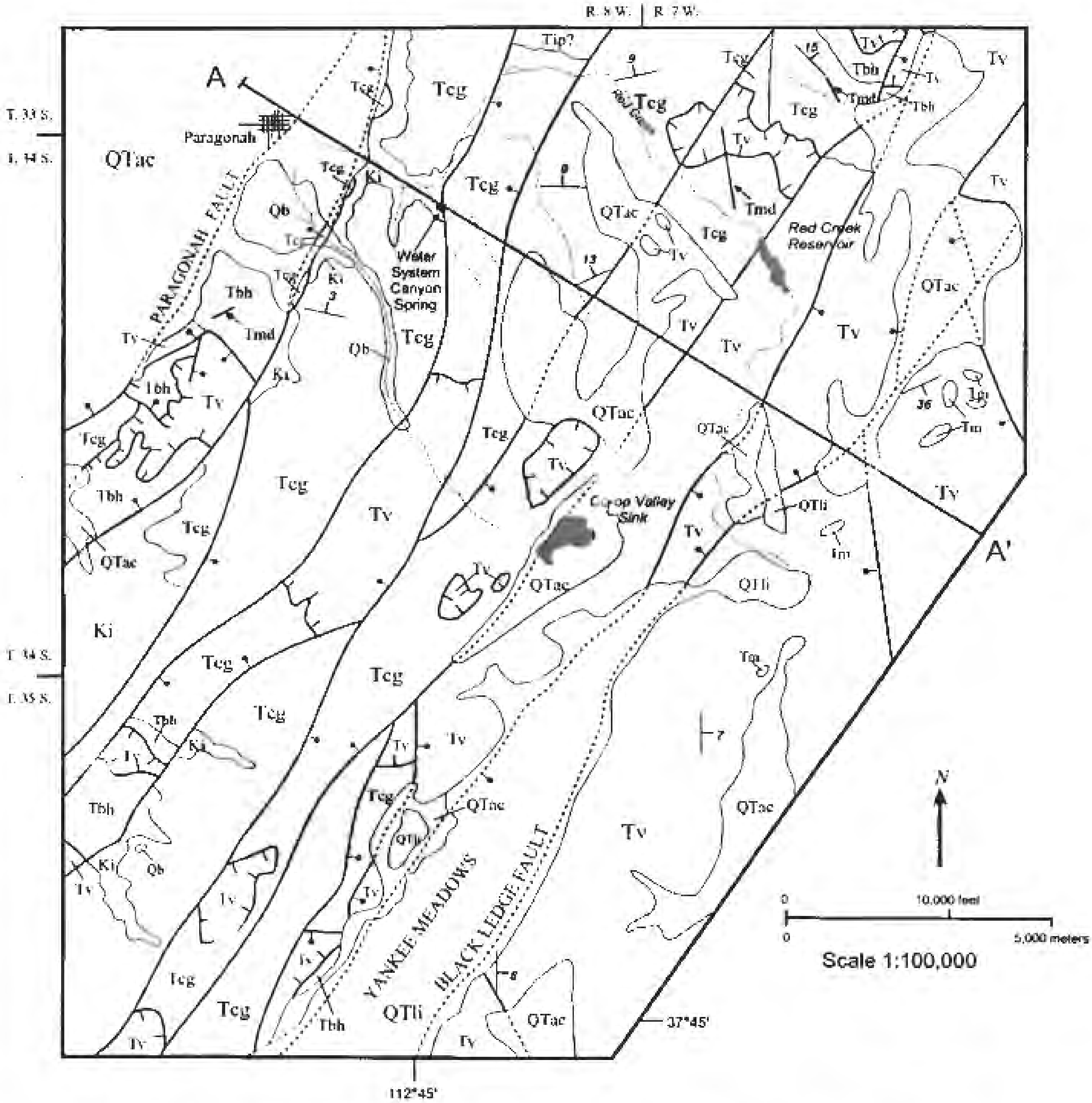
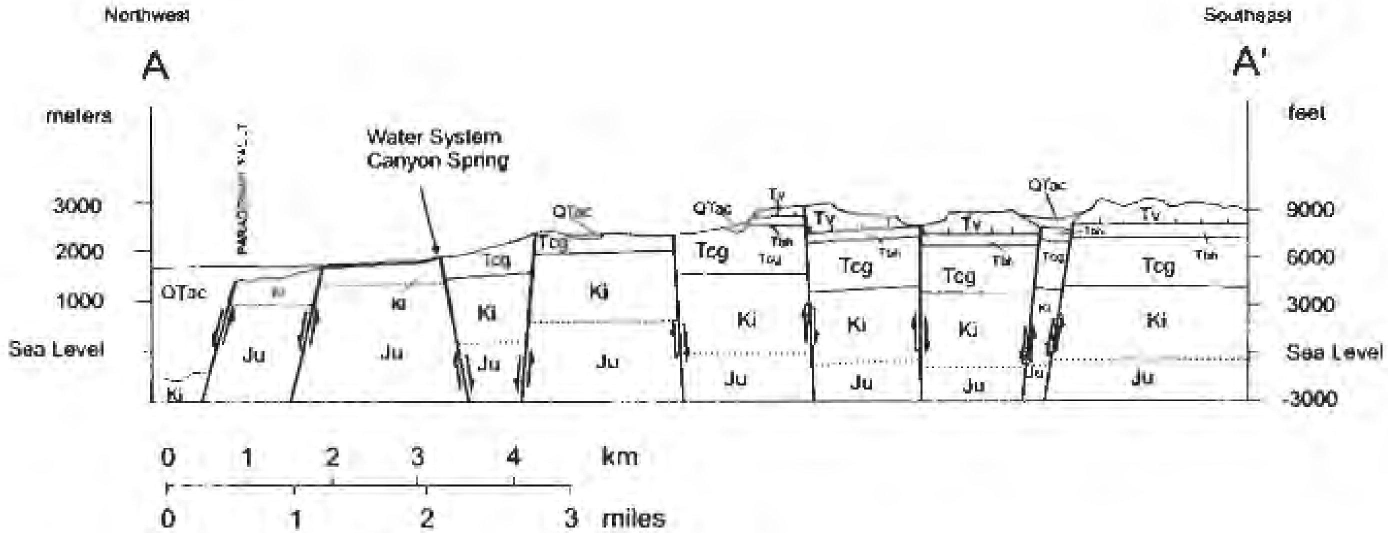


Figure 2. Geologic map of part of the northern Markagunt Plateau (after Maldonado and others, 1997). Explanation on following page. Cross section A-A' shown on figure 3.

EXPLANATION

Qb	Quaternary basaltic volcanic rocks
QTac	Quaternary and Tertiary alluvium and colluvium
QTli	Quaternary and Tertiary(?) landslide deposit predominantly of Isom Formation
Tm	Miocene megabreccia blocks - Gravity-slide blocks composed of Tertiary volcanic and sedimentary rocks.
Tmd	Miocene mafic dike—Not all dikes shown
Tip	Miocene intrusive and associated rocks of Iron Peak laccolith--Gabbroic body and mafic dikes
Tv	Miocene and Oligocene volcanic rocks, undivided---Includes Harmony Hills Tuff, Bauers Tuff Member of Condor Canyon Formation, and Leach Canyon, Mount Dutton, and Bear Valley Formations, mudflow and lava-breccia and tuffaceous sandstone unit, Isom, Lund, and Wah Wah Springs Formations. (Includes Brian Head Formation locally.) Composed mostly of ash-flow tuff and some tuffaceous sandstone and volcanic mudflow breccia.
Tbh	Oligocene and Eocene Brian Head Formation---Composed mostly of sandstone, tuffaceous sandstone, mudflow breccia, pebble-boulder conglomerate, and minor limestone, limy shale, and local ash-flow tuff.
Tcg	Eocene-Paleocene Claron Formation and Paleocene Grand Castle Formation—Sandstone, siltstone, limestone, and conglomerate.
Ki	Cretaceous Iron Springs Formation---Sandstone, siltstone, shale, and conglomerate.
	Contact
	Normal fault---Dotted where concealed; bar and ball on downthrown side where known.
	Red Hills low-angle shear zone---Dotted where concealed; hachures on upper plate.
59	Strike and dip of beds
A — A'	Line of cross section.

Figure 2 (continued). Explanation for geologic map of the northern Markagunt Plateau (after Maldonadao and others, 1997).



QTac	Quaternary and Tertiary alluvium and colluvium
Tv	Miocene and Oligocene volcanic rocks
Tbh	Oligocene and Eocene Brian Head Formation
Tcg	Eocene-Paleocene Claron Formation and Palocene Grand Castle Formation
Ki	Cretaceous Iron Springs Formation
Ju	undifferentiated Jurassic rocks (includes the Carmel Formation, Temple Cap Formation, and Navajo Sandstone)

Contact, dashed where uncertain

Normal fault, arrows show relative movement

Red Hills low-angle shear zone

Figure 3. Geologic cross section trending northwest through Water System Canyon Spring. See figure 2 for location.

Overlying the Claron Formation is the heterogenous assemblage of Oligocene to Eocene sedimentary (mostly sandstone) and volcanic strata of the Brian Head Formation (Sable and Maldonado, 1997). During the late Eocene and intermittently through the Oligocene and Miocene, 1,500 to 2,000 feet (457-610 m) of volcanic rock was deposited on the eroded surface of the older sedimentary rocks (Anderson, 1965). Isolated mafic dikes and other igneous rocks were intruded along northwest-trending faults during the Miocene (Maldonado and others, 1997). Surficial sediments near Water System Canyon Spring are poorly sorted fluvial sand, silt, and clay, and talus. The Holocene surficial sediments mantle the Eocene-Paleocene Claron Formation, Paleocene Grand Castle Formation, and a Pleistocene lava flow.

Approximately 15 miles (24 km) wide, the Markagunt Plateau is a structurally complex area containing an extensive network of northeast-trending grabens and half grabens. Considerable insight into the structure of the area has been gained by recent studies in the area (Maldonado and Williams, 1993; Maldonado and others, 1997; Nealey and others, 1997; Sable and Maldonado, 1997). East-directed thrust faulting during the Cretaceous Sevier orogeny produced a foreland basin that occupied the area. The latest Cretaceous to Paleogene Laramide orogeny deformed the Sevier foreland basin and produced isolated, internally drained basins separated by thrust-bounded uplifts. The Claron Formation represents sediments deposited in one of these isolated basins. Post-Laramide fragmentation and volcanism associated with Basin and Range extension occurred within the last 30 million years. The Brian Head Formation provides a record of the earliest extensive post-Laramide volcanism in southwestern Utah (Feist and others, 1997).

Northeast-trending high-angle faults that cut 20-million-year-old intrusive rocks and truncate other structural features are the youngest structures in the northern Markagunt Plateau (Maldonado and others, 1997). The high-angle faults bound the graben systems and include subsidiary and minor antithetic and synthetic faults between major bounding faults. Faults and associated fracture systems are zones of weakness that have been subsequently weathered and eroded, forming aligned valley segments, ridges, depressions, and other diagnostic landforms. Faults also locally control the locations of Pleistocene basalt.

Major geologic features of the Markagunt Plateau include numerous faults, generally flat-lying sedimentary rocks within drown-dropped faulted blocks of various sizes, volcanic rocks forming the tops of the mountains and ridges, and the stream-dissected western slope of the mountains. Fault-bounded drainages in higher areas are surrounded by high ridges that form long, narrow, closed-surface, high mountain valleys. These areas have no major surface drainage outlets and a large part of the precipitation that falls within them infiltrates into the ground. Volcanic rocks are at the surface or lie beneath a thin mantle of stream and terrace gravels in these valleys. Some volcanic rocks are exceedingly porous, because they are fractured and have cavities. In places, the rocks have slumped to form depressions or sinks that serve as collection basins for water in the high mountain valleys. Ground water flowing through fractures has modified them, and some features may have been formed by ground-water circulation along fault/fracture systems.

Outcrops above the spring were examined for evidence of faulting, but none was identified at outcrop scale; however, fault traces in the spring area can be identified from aerial photographs and topographic maps of the area. Although little is known about the fracture network in the area, fractures were observed in outcrops near the spring. Fractures are considered the principal source of secondary porosity and permeability in the rocks. Fractures are relatively abundant in certain lithologies and unidentifiable in other lithologies. Fractures were measured only in sandstone outcrops, because of sparse fracture densities in conglomerate, siltstone, and claystone in the area. Stratigraphic units that crop out near Water System Canyon Spring strike about N. 80° W. and dip 3° to 5° to the northeast. Fractures observed in outcrop occur as two variable sets, both at a high angles to bedding. Dominant fracture sets measured at two different outcrops near the spring trend roughly N. 13° W. and N. 5° W. (figures 4 and 5). Secondary fracture sets trend N. 47° W. and N. 25° W. Fracture spacing in outcrops in this area is generally 8 to 18 inches (46-122 cm) for the dominant fracture set and 9 to 14 inches (23-36 cm) for the secondary fracture set. Fractures are generally traceable across individual outcrops. However, few outcrops could be examined because of the steep, cliff-forming topography.

CLIMATE

Paragonah is at the eastern edge of Parawon Valley and has a relatively equable climate characterized by warm, dry summers and cool winters with small amounts of rain and snow. Water System Canyon Spring is east of Paragonah, in the mountains, where the climate is semiarid to humid and characterized by low precipitation, rapid evaporation, and a wide range of temperatures. The average mountain precipitation is probably higher than at Paragonah, but no accurate information is available to compare. Precipitation in the mountains is erratic, particularly in late spring, summer, and

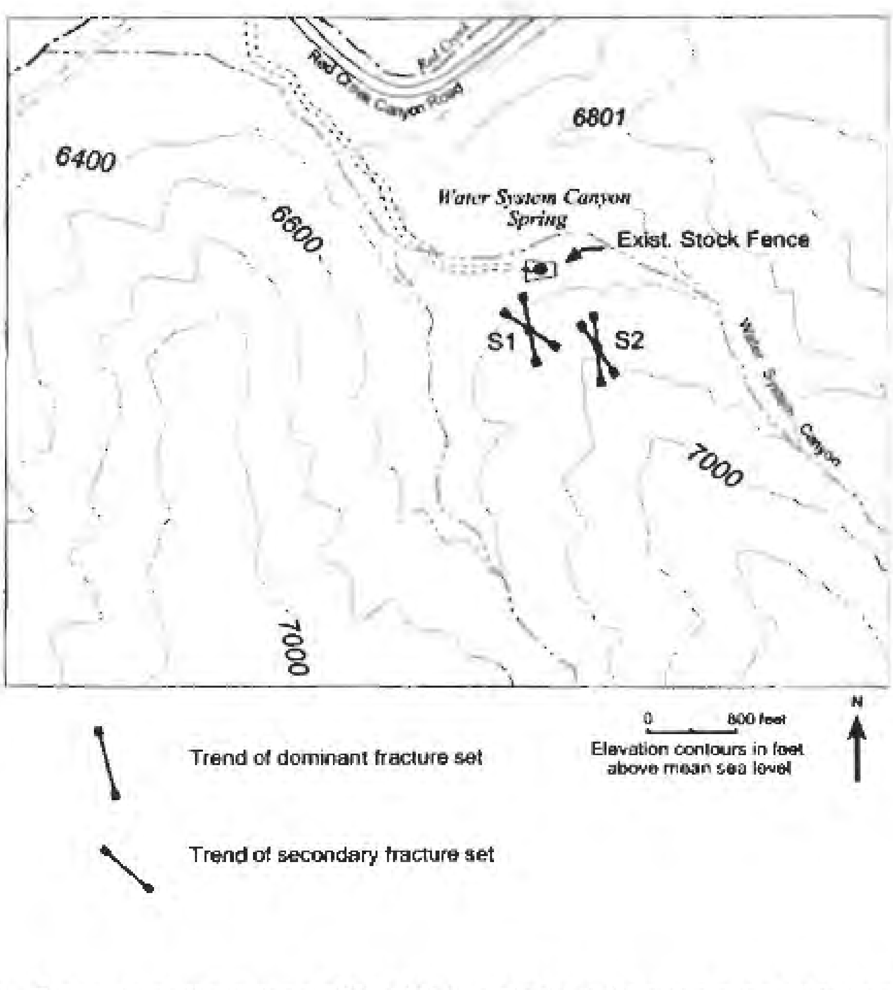
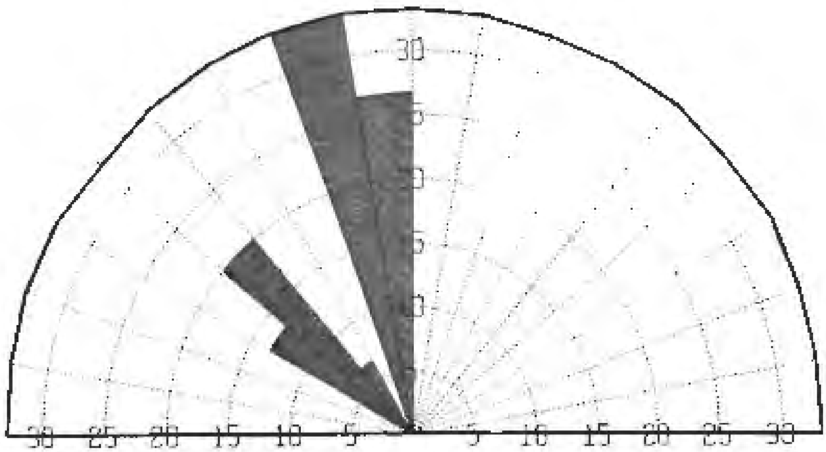
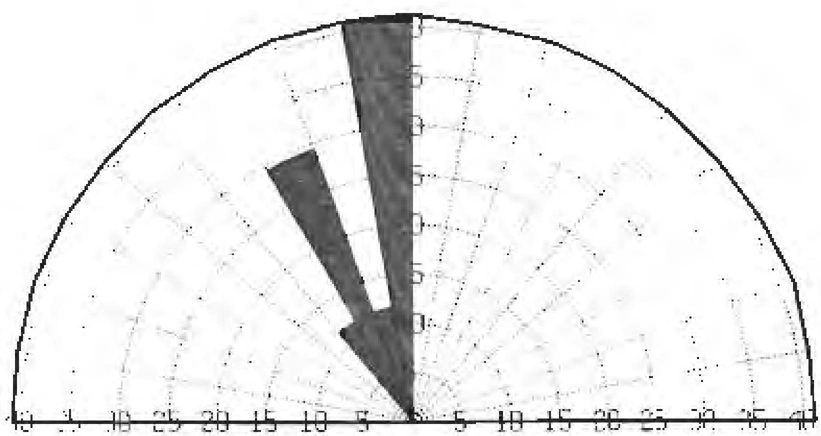


Figure 4. Fracture-pattern map of the Water System Canyon area showing trends of fractures at measurement sites (S1 and S2).



S1



S2

Figure 5. Rose diagrams depicting fracture orientation in surface drainage area surrounding Water System Canyon spring.

early fall, and is characterized by an irregular areal distribution that commonly does not extend to the lower valleys (Gregory, 1950). Much of the precipitation occurs as heavy thundershowers in July, August, and September.

The nearest weather observation stations (data are collected at National Oceanic and Atmospheric Administration [NOAA] climatological stations) to Water System Canyon Spring are at Parowan, 5 miles (8 km) west of the spring, and Panguitch, 18 miles (29 km) southeast of the spring. The elevation of the Parowan weather station is about 6,000 feet (1,829 m) and the Panguitch weather station is at about 6,720 feet (2,050 m). Water System Canyon Spring is at an elevation of 6,470 feet (1,972 m) and much of its recharge area is above 9,000 feet (2,700 m). Parowan, at the base of the Markagunt Plateau, is 470 feet (143 m) lower in elevation than Water System Canyon Spring. Panguitch, in a back valley to the Markagunt Plateau, is 250 feet (76 m) higher than Water System Canyon Spring.

Monthly temperature and precipitation data from the Parowan and Panguitch NOAA weather stations are given in table 1. The mean annual temperatures at Parowan and Panguitch are 48.7 °F and 43.9 °F, respectively, with average annual precipitation of about 13 and 10 inches (33 and 25 cm), respectively. Locally, mountain precipitation may average 20 to 25 inches (51-64 cm) annually (Ashcroft and others, 1992). Snowfall in the mountains is considerably greater than in the lower valleys and total annual precipitation along the western Markagunt Plateau probably exceeds 35 inches (89 cm) (Gregory, 1950). Neither the Panguitch nor Parowan weather stations are considered completely representative of climatic conditions near Water System Canyon Spring, and are not at all representative of the mountains above the spring. Annual evapotranspiration is about 48 inches (122 cm) in the Parowan and Panguitch area and about 23 inches (58 cm) in the mountains (Ashcroft and others, 1992).

Mountain snow cover is usually present from mid-November to mid-May and the precipitation received as snow on the higher elevations is an important factor in recharging ground water (Thomas and Taylor, 1946). The slow melting of winter snow is favorable for the replenishment of soil moisture and ground-water recharge. Average annual snowfall at the elevation of the recharge area, approximately 9,000 feet (2,750 m), ranges from 40 to 109 inches (102-277 cm) (Thomas and Taylor, 1946; Gregory, 1950). The water content of the snow is generally about one-third of the snow depth.

Average annual precipitation at Paragonah is probably close to that of Parowan, about 13 inches (33 cm). Evapotranspiration exceeds precipitation at Parowan and Panguitch, and most likely at

	Panguitch				Parowan				
	Maximum *Temp. °F*	Minimum *Temp. °F*	Average *Temp. °F*	Precip (inches)	Maximum *Temp. °F*	Minimum *Temp. °F*	Average *Temp. °F*	Precip (inches)	
Jan	40.4	8.2	24.3	0.5	42.0	14.4	28.2	0.87	Jan
Feb	44.6	13.7	29.1	0.65	46.3	19.3	32.8	1.13	Feb
Mar	51.2	19.2	29.7	0.75	52.1	24.9	38.5	1.49	Mar
Apr	60.0	24.7	42.35	0.67	60.3	31.7	46.0	1.37	Apr
May	69.4	31.6	50.5	0.79	70.1	39.3	54.7	0.88	May
June	79.7	38.5	59.1	0.65	81.4	47.7	64.5	0.57	June
July	85.1	45.8	65.4	1.48	87.2	54.6	70.9	1.26	Jul
Aug	82.3	44.6	63.4	1.75	84.8	52.8	68.8	1.52	Aug
Sept	75.8	36.1	55.9	1.07	77.4	44.1	60.8	0.95	Sept
Oct	65.9	26.4	46.2	0.75	66.5	33.8	50.2	1.02	Oct
Nov	52.0	17.8	34.9	0.73	52.8	24.0	38.4	1.14	Nov
Dec	41.8	9.7	25.8	0.55	43.1	15.7	30.4	0.94	Dec
Average Temperature 43.9					Average Temperature............. 48.7				
Average annual precipitation.......10.34					Average annual precipitation........13.14				

Table 1. Summary of temperature records, in degrees Fahrenheit, and annual precipitation, in inches of water, as available from 1961 to 1990 (data from National Oceanic and Atmospheric Administration's Panguitch and Parowan Climatological Stations).

Paragonah as well. The average annual precipitation at Water System Canyon Spring is probably about 13 to 15 inches (33-38 cm) and evapotranspiration probably also exceeds precipitation there. Average annual precipitation in the mountains above Water System Canyon Spring is between 20 and 35 inches (51-89 cm) and can exceed 35 inches (89 cm) in the higher mountains. Average annual evapotranspiration in the range of elevations found in the recharge area of the spring is about 23 inches (58 cm) (Ashcroft and others, 1992).

SPRINGS

Springs are an important source of water in the Red Creek Canyon region. They range from mere seeps to excellent springs that flow up to several hundred gallons of water per minute (figure 6). Springs in Red Creek Canyon and its tributaries are of three kinds: (1) springs associated with faults that flow due to hydraulic head associated with confined conditions under pressure, (2) springs associated with faults that flow because of gravity, and (3) springs not associated with faults that flow because of gravity. Some springs are well developed and their waters are utilized to the greatest possible extent; others are not developed or used. Water System Canyon Spring is located in Water System Canyon, which is a tributary to Red Creek Canyon. The spring is at a surface elevation of approximately 6,470 feet (1,972 m). It is one of several springs on the south side of Red Creek Canyon having similar characteristics (table 2).

Cool Spring, approximately 3 miles (5 km) east of Water System Canyon Spring, flows from alluvial deposits on the canyon side and is along the trend of a regional fault. Cool Spring has a small intermittent discharge that appears to be controlled by the release of water from Red Creek Reservoir. The spring discharge increases shortly after water is released from the reservoir spillway into Red Creek, indicating that water is transferred rapidly along a fault under gravity conditions.

South Fork Spring discharges from colluvium in the bottom of South Fork of Red Creek Canyon approximately 1.5 miles (2.5 km) east of Water System Canyon Spring. Discharge rates at South Fork Spring are reported to vary seasonally. South Fork Spring was part of the Paragonah public-water-supply system but had water quality (turbidity) problems. South Fork Spring discharge is reportedly affected by water released through a diversion tunnel of a reservoir 4 miles (6.4 km) south

Site	Location	Elevation (feet)	Discharge	Characteristics of springs
Cool Spring	T. 34 S., R. 7 W., section 7	7,520	Variable, with small yields.	One spring with small area of seepage at side of canyon beneath a cover of colluvium. Localized shallow flow system within the Claron Formation.
Warm Springs	T. 33 S., R. 8 W., section 36	6,880	Constant, with large yields. The westernmost spring produces about 600 gal/min	Three springs with large areas of seepage at the bottom of canyon beneath alluvium. Intermediate to possible regional deep-flow system associated with fault/fracture systems and bedding contact.
South Fork Spring	T. 34 S., R. 8 W., section 2	6,790	Variable, with yields greater than 200 gal/min, but water quality can be a problem.	One spring with small area of seepage at bottom of canyon beneath a cover of colluvium. Intermediate, moderate-depth flow system associated with a fault/fracture system and a contact within the Claron Formation.
Water System Canyon Spring	T. 34 S., R. 8 W., section 3	6,470	Variable, with good yield of about 200 gal/min.	One spring with small area of seepage at side of canyon beneath a cover of colluvium. Intermediate, moderate-depth flow system associated with a fault/fracture system and a contact with lava flow within the Claron Formation.

Table 2. Characteristics of springs in the vicinity of Water System Canyon Spring. Locations are referenced to the Salt Lake Base Line and Meridian.

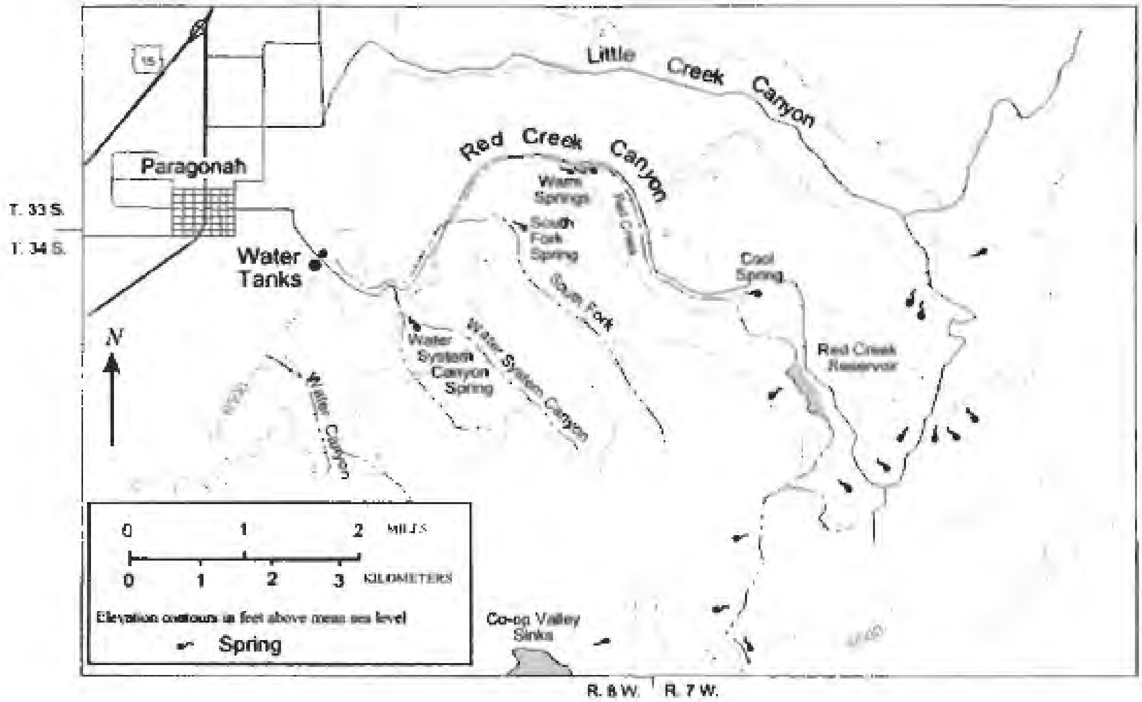


Figure 6. Locations of springs in the study area.

of the spring; the spring becomes muddy within a few days of the release of water (Constance Robinson, Mayor of the town of Paragonah, verbal communication, 1997).

Warm Springs is a group of springs approximately 2 miles (3 km) northeast of Water System Canyon Spring. The springs discharge from the alluvium in the bottom of Red Creek Canyon. Their discharge appears to be constant throughout the year and hydrostatic pressure along a fault apparently controls their flows. One spring in the Warm Springs group is part of the Paragonah public-water-supply system.

Water System Canyon Spring issues from colluvial gravel deposits on the side and bottom of Water System Canyon, near where the canyon splits into two branches. The spring is near outcrops of Claron Formation and a basalt flow. Determining exactly which rock unit the spring issues from is not possible because of ground cover. Prior to development of the spring the water came to the surface, forming a small wet area with flowing water, which collected and drained into Water System Canyon and then to Red Creek. Water System Canyon Spring flow averages about 200 gallons per minute (gal/min), but is affected by seasonal variations in precipitation. The town of Paragonah uses the spring as part of its public-water supply (Constance Robinson, verbal communication, 1997).

Water System Canyon Spring is well developed, and its water is utilized completely with no surface run off. The collection system for Water System Canyon Spring is in fluvial and slope-wash deposits on the side and bottom of the canyon, within 10 feet (3 m) of the contact between bedrock and the unconsolidated deposits. The area around the spring has been built up and leveled. Vegetation covers and surrounds the spring area. To collect the spring water, perforated pipes were laid in gravel-lined ditches in the vicinity of the spring and backfilled. The collection pipes feed to a collection box, then into the city water-supply system. The spring box provides a settling basin for sediment removal and facilitates maintenance of the spring. The spring discharge is piped about 1 mile (1.6 km) to the northwest to Paragonah water tanks.

Other springs are found at higher elevations throughout the area (figure 6). The locations of these springs are taken from the U.S. Geological Survey Red Creek Reservoir 7.5-minute quadrangle map. These springs are maintained by precipitation in the mountains and localized gravity flow systems; during the dry seasons their flow volume diminishes. For the most part, these springs are small and are not utilized except for livestock watering.

HYDROGEOLOGY

Analyses of the bedrock terrain in the area indicate that high-yielding springs are along highly developed permeability zones associated with fault/fracture systems. The regional fault/fracture systems of the northern Markagunt Plateau evidently operate as significant ground-water drains. Ground-water is collected in the fault/fracture systems from higher elevations and then flows toward discharge points also associated with the fault/fracture systems. The ground-water system is composed of two principal components: (1) highly anisotropic and heterogeneous fault/fracture-controlled water-transmitting zones that function as aligned sinks and discharge points throughout the plateau, and (2) the intervening, relatively lower permeability (compared with the fault/fracture systems) sedimentary and volcanic rock masses that drain toward the fault/fracture systems. Ground-water flow is not necessarily parallel to the principal trends of fault/fracture systems; however, ground water does travel preferentially along fault/fracture systems. There is no truly distinct layered aquifer system in the region but rather one continuous aquifer, associated with the fault/fracture systems, with isolated non-saturated zones throughout the system.

In rocks of low to moderate matrix permeability, like those found in the region, all significant regional ground-water flow is within fault/fracture systems, and to a lesser extent along bedding planes and lithologic contacts. Major ground-water flow in the region is very heterogeneous and focused predominately within permeable intervals dominated by fractures. The average transmissivity of the highly permeable intervals is substantially larger than less permeable intervals. When eroding topography intercepts one of these highly permeable intervals a spring can occur. Water System Canyon Spring occurs along one of these fault/fracture intervals where ground water escapes into overlying unconsolidated deposits. Nearly all of the discharge from Water System Canyon Spring originates from one of these fault/fracture intervals, but flow to the fault/fracture interval is partially derived from the rock matrix (mostly from bedding planes and lithologic contacts) which provides important storage porosity.

Topographically high outcrop areas and fault/fracture systems control the regional ground-water-flow pattern. The relatively high permeability zones, associated with fault/fracture systems, connect higher areas, and the hydraulic head associated with these areas, to lower areas. The fault/fracture system fills with water and exerts hydrostatic pressure on the lower parts of the aquifer. In some areas the fault/fracture system transmits water, but in other areas lower permeability intervals isolate the fault/fracture system. These lower permeability intervals divide the fault/fracture systems into compartments of different sizes with water-yielding capacities that vary from place to place. Where parallel fault/fracture systems supply individual springs, they limit the area drained by each spring.

The hydrogeologic properties and distribution of the rocks, together with topography, impose strict controls on areas contributing recharge to the ground-water system and to the springs. Recharge occurs preferentially along the fault/fracture systems exposed at the land surface and through rocks in the hanging walls of the fault/fracture systems. The permeability of the terrain is highly variable and the infiltration of water into the ground is high in some areas, and moderate or low in others. The sedimentary and volcanic rocks exposed at the surface of the Markagunt Plateau seem to be an excellent recharge media and likely conduct much of the precipitation that falls on the plateau directly into the ground-water system. Recharge takes place through open fractures at the surface and below shallow soil cover, and the numerous depressions that are found at the surface. In areas were rocks have formed depressions or sinks, or the topography has been modified by ground-water circulation, highly conductive areas serve as effective conduits for direct recharge to some springs. The location of large springs in the Red Creek drainage area indicates ground-water flow is from the south toward the north. The westward-sloping mountain front of the Markagunt Plateau probably also provides a westward component of ground-water flow in the Water System Canyon Spring area. Data indicating boundaries to ground-water flow, as well as data that would indicate flow properties, are unavailable for the aquifer.

Water System Canyon Spring discharges from alluvium and colluvium in and near the channel of Water System Canyon. Discharge may be caused by the redirection of ground-water flow by less permeable rock, or by breaching of the impermeable rock. The relatively impermeable basalt in the area could be a confining unit or perhaps redirects ground water to the spring. Bedrock in the bottom of Water System Canyon is covered by alluvium which has a thickness of 0 to about 25 feet (0-8 m). The alluvium is underlain by the Eocene-Paleocene Claron Formation and Paleocene Grand Castle Formation. Tertiary rocks exposed at and near the ground surface are underlain by Jurassic rocks at shallow depths, which are known to be productive aquifers in other parts of southwestern Utah. Ground water in the subsurface may be shunted upward to mix with other shallower ground water and discharge at the surface where the basalt is breached. The variable discharge of Water System Canyon Spring indicates that the spring is, at least in part, fed by a local to intermediate flow system.

Geochemical Characterization

Delineation of ground-water flow paths is difficult to accomplish in areas lacking physical aquifer parameters to constrain hydrologic interpretation. To help constrain and delineate ground-water flow paths I evaluated the Utah Division of Drinking Water, Department of Environmental Quality, chemical data for the spring. Water System Canyon Spring water is characterized by low concentrations of dissolved solids, ranging from 190 to 230 mg/L, and pH ranging from near neutral to alkaline, between 7.6 and 9.0 (table 3). Low dissolved solids and near-neutral to slightly alkaline pHs are typical in water with short to moderate residence times, which allow some water-rock interaction. Chemical constituents in Water System Canyon Spring water are derived principally from the dissolution of sedimentary carbonate minerals and sedimentary and volcanic siliceous minerals.

The ground-water chemistry in June 1978 was generally similar to the ground-water chemistry of July 1992, as indicated by the similar concentrations of calcium, magnesium, potassium, and silica (table 3). Trilinear plots of ground-water chemistry data for samples collected in June 1978 and July 1992 fall into a single grouping (figure 7). Based on major ion proportions for the spring water, the water is a calcium-magnesium-bicarbonate type. For cations, the samples show high calcium concentrations relative to sodium and magnesium concentrations. For anions, the samples show high bicarbonate concentrations relative to sulfate and chloride concentrations. The most notable differences between the water samples are that sulfate, bicarbonate, and total dissolved solids (TDS) concentrations increased from June 1978 to July 1992. Sulfate ion concentrations are higher than chloride concentrations. Fluctuation in the concentration of sulfate discharging from the spring probably represents changes in the relative amounts of water in contact with sulfate compounds along flow paths to the spring.

The spring water has a high concentration of Ca^{+2} ions and therefore high hardness; however, the overall quality of the water is good. The Ca^{+2}/Mg^{+2} ratios suggest that ground water flows through a mixed carbonate terrain, dominated by limestone. The moderate relative concentration of sodium is probably due to the hydrolysis of volcanic silicates, which indicates a moderate to substantial residence time. Sulfate concentrations indicate water has had contact with sulfate-bearing minerals, like gypsum found in some Jurassic rocks of the area. The relatively high sulfate and sodium concentrations could indicate that some ground water at the spring travels along a deep flow path, and possibly deeper water mixes with shallower water.

	06-13-78	08-12-86	07-28-92
Calcium (mg/L)	40.0	-	46.0
Magnesium (mg/L)	17.0	-	24.0
Potassium (mg/L)	2.0	-	1.0
Sodium (mg/L)	11.0	-	8.0
Bicarbonate (mg/L)	217	-	252
Carbonate (mg/L)	<1	-	0
Chloride (mg/L)	12.0	5.0	8.0
Fluoride (mg/L)	0.27	0.22	0.21
Phosphorus (mg/L)	-	-	0.02
Silica (mg/L)	14.0	-	12.0
Sulfate (mg/L)	4.0	11.0	14.0
pH	7.6	9.0	7.9
TDS@180°C (mg/L)	190	-	230
Specific conductance (μmho/cm)	290	-	425

- *no data available*

Table 3. Analytical results for water samples from Water System Canyon Spring.

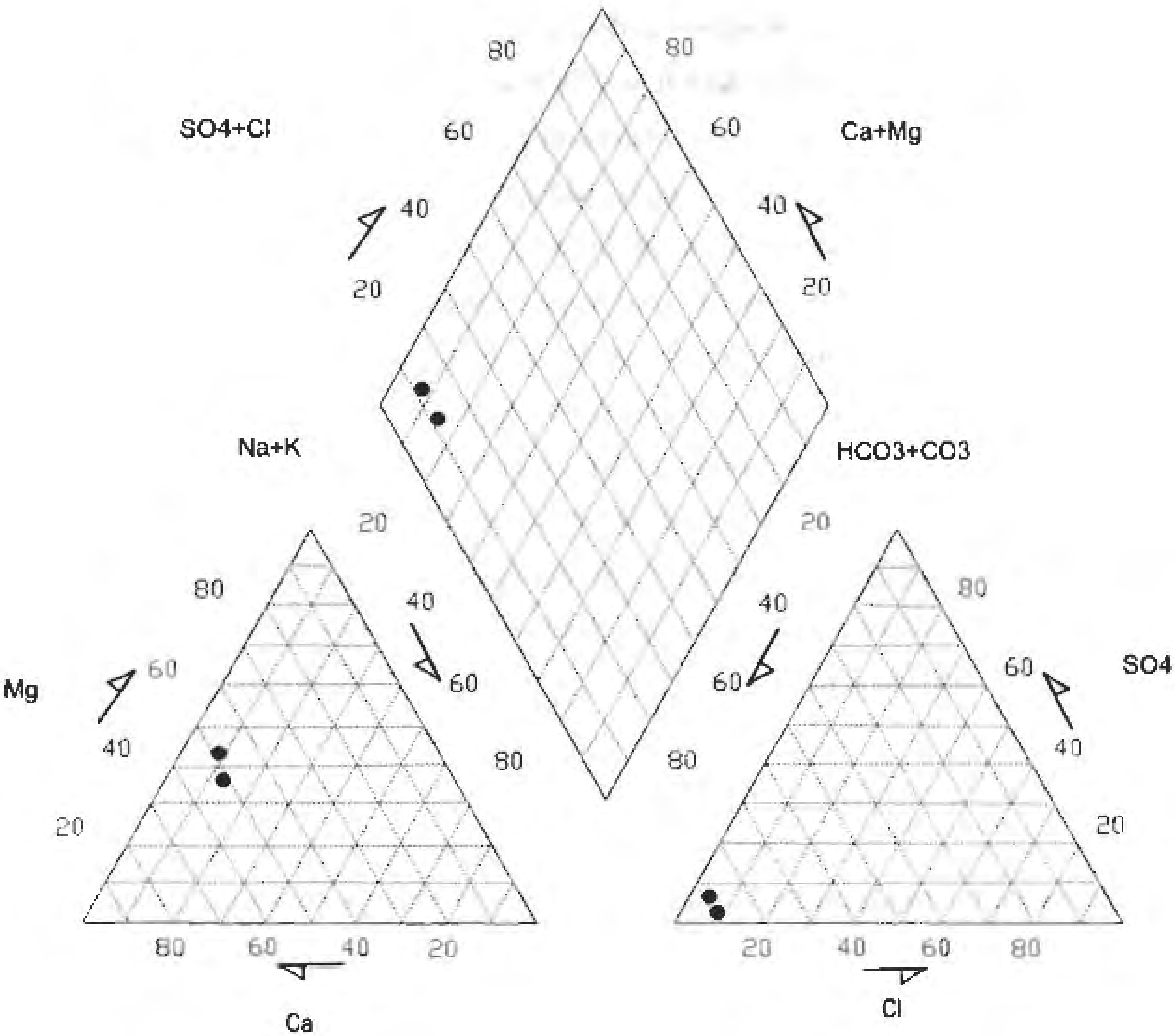


Figure 7. Trilinear diagram depicting geochemical analyses of water samples from Water System Canyon Spring.

Water System Canyon Spring has never exhibited any water quality problems, like South Fork Spring has (Constance Robinson, verbal communication, 1997). This would indicate that the fracture network does not act as a direct conduit for ground water from higher elevations. Also, the lack of large variation in Water System Canyon Spring water chemistry suggests that the residence time is enough to buffer chemical variations in the recharge area. The chemistry of the discharge water indicates that water enters the system and then moves at a relatively slow rate while interacting with the volcanic and sedimentary rocks of the area. The chemical composition of the ground water can be explained by local to intermittent ground-water flow paths (primarily with short to moderate residence times), or the mixing of waters from a deep flow system and a shallower flow system (long-residence-time water with short-residence-time water). However, if there was a substantial component of deeper circulating ground water, higher concentrations of sodium and sulfate would be expected. The observed shift of water chemistry from June 1972 to July 1992 could indicate that the contribution of deep ground water may be episodic, related to recharge events.

The chemical data suggest spring water originates from recharge water that has reacted with calcite, and to some extent silicate minerals in the rocks upgradient from the spring. The water is in the ground-water system long enough to buffer any changes in recharge, but not long enough to dramatically lower the quality of the water. This would indicate that the system is in part acting equivalent to a heterogeneous and anisotropic porous media where water infiltrates into the ground above the fracture network, recharges the aquifer, reacts with the surrounding rocks while moving down gradient, and discharges at the spring.

Hydrologic Budget

I developed a simple hydrologic budget for the Red Creek catchment area. This is a mostly semiarid area of about 16 square miles (41 km^2). The budget assumes all water entering the catchment area either goes into storage within its boundaries, is consumed therein, or flows out either on the surface or underground. Bjorklund and others (1978) identified precipitation as the principal source of water in the Parowan Valley watershed. Evapotranspiration, and surface and ground-water flow out of the watershed, dominate and control all other hydrologic variables.

Precipitation in the catchment area ranges from 14 to 35 inches (36-89 cm) annually and probably averages 25 inches (63 cm), thus inflow to the catchment area is about 929.3 million ft^3/yr (26 million m^3/yr). The temporal and spatial variation of annual, seasonal, and monthly precipitation is not evenly distributed within the catchment area. Higher precipitation is associated with summer and fall convective storms and higher elevations. Evapotranspiration, the largest outflow from the catchment area, includes losses by transpiration from plants, and evaporation from the ground or snow surfaces. Evapotranspiration averages about 23 inches (58 cm) annually over the catchment area, accounting for the loss of about 855 million ft^3/yr (24 million m^3/yr) of water from the catchment area. Like precipitation, the temporal and spatial variation of evapotranspiration is not evenly distributed within the watershed. Bjorklund and others (1978) estimated Red Creek outflow, at Paragonah, to average about 209.1 million ft^3/yr (6 million m^3/yr). A relatively small amount of ground water leaves the catchment area by subsurface outflow into the Parowan Valley alluvial fill. According to Bjorklund and others (1978), about 17.42 billion ft^3/yr (493 million m^3/yr) of water recharges Parowan Valley, and at most 10 percent, or 1.7 billion ft^3/yr (48 million m^3/yr), is subsurface inflow from the mountains. The mountain front within the Red Creek catchment area is between 2 and 3 percent of the total mountain front of Parowan Valley, so about 42.5 million ft^3/yr (1 million m^3/yr) of water could leave the Red Creek catchment area as subsurface outflow.

The average hydrologic budget for the Red Creek catchment area indicates discharge exceeds recharge by 177.2 million ft^3/yr (5 million m^3/yr). This difference between recharge and discharge of water cannot be accounted for in the estimated hydrologic budget; springs supplying water from an aquifer larger than the catchment area is a likely source of this additional water. Water is probably being channeled up from deeper aquifers along some of the fault/fracture systems, and part of this water originates outside the Red Creek catchment area.

Catchment Area Calculations

Hypothetical catchment areas can be estimated using analytical methods based on recharge and discharge (Todd, 1980). As indicated above, average annual precipitation in the mountains can be conservatively estimated at 25 inches (63 cm) and evapotranspiration can be estimated at 23 inches (58 cm). The amount of recharge is the difference between precipitation and evapotranspiration, or 2 inches (5 cm). This represents about 8 percent of the total precipitation.

In the entire catchment area total discharge from springs is as much as 2,200 gal/min (138.8 L/sec). Using the method of Todd (1980) to plot catchment area as a function of estimated recharge rate and discharge from springs, a catchment area of about 57.2 square miles (150 km^2) would be necessary to supply enough water for all the springs in the Red Creek drainage area. The topographic catchment area for Red Creek, in which Water System Canyon Spring is located, is about 16 square miles (41 km^2). The discharge of Water System Canyon Spring is estimated at about 200 gal/min (12.6 L/sec). Using the method of Todd (1980), a catchment area of about 3.5 square miles (9 km^2) would be necessary to provide enough water for Water System Canyon Spring.

DWSP ZONES

To maintain the quality of the water from Water System Canyon Spring, which is of particular concern to Paragonah Municipal Water Company, the surface and subsurface areas supplying water to the spring need to be protected. The delineation of capture zones, or DWSP zones, is a method of identifying areas surrounding the spring that should be protected against infiltration, percolation, and transport of contaminants that may have adverse effects on human health. Time-related protection zones may be generated inside the delineated spring capture zone for any time period. Because of the vague characterization and lack of physical parameters to construct hydrologi. interpretation of the aquifer, uncertainties need to be incorporated into strategies for delineating time-related protection zones for the spring.

Based on the geological and hydrogeological evaluation, I made the following assumptions regarding aquifer characteristics relevant to capture-zone delineation:

- Extensive fault/fracture systems and topography are important factors controlling the supply of ground water to Water System Canyon Spring.
- The fault/fracture system accepts drainage from the surrounding rocks and conducts the water to the spring.
- The ground-water flow system has a high degree of heterogeneity and anisotropy with an increased potential for ground-water movement to the spring from the south to the north, based on fault and fracture orientations; however, on the western slopes of the Markagunt Plateau there is probably a westward component of ground-water flow.
- The ground-water chemistry indicates the spring water has a short to moderate residence time.

- The hydrologic system may be obtaining part of its water from a porous-media reservoir at depth on a scale larger than the drainage basin.
- Extensive fault/fracture systems in the exposed bedrock may indicate a relatively high degree of vulnerability of the ground water to contamination.
- Hydraulic conductivity and, potentially, ground-water velocity may be relatively high in parts of the system.
- Ground-water divides are not readily defined in the area.

The hydrogeologic budget and catchment area calculations indicate that springs in the area obtain part of their ground water from deeper regional aquifers. I believe that part of the ground-water discharge from Water System Canyon Spring may also come from a deeper regional aquifer, but Water System Canyon Spring obtains most of its water from shallower sources. The ground-water chemistry supports this. The catchment area for Water System Canyon Spring may encompass a substantial part of the surface drainage basin and is too large an area to be effectively managed by the Paragonah Water Company. However, due to uncertainties, delineated capture zones must be sufficiently conservative (protective) to guarantee success.

Hydrogeologic Method

Current spring protection plans require the determination of areas contributing recharge to the spring. Flow paths to the spring depend on the hydrologic characteristics of the aquifer, boundary conditions of the flow system, and location and discharging rate of the spring. The only theoretical limit to the areal extent of ground-water flow is the physical boundaries of the ground-water system; however, no ground-water flow boundaries could be inferred from this study.

The surface area or capture zone contributing to Water System Canyon Spring is delineated by identifying areas, predominantly the fault/fracture system, that contribute ground-water flow to the spring from areas that do not contribute ground-water flow to the spring. Fault/fracture systems and areas of higher topography control the potentiometric-surface gradients of the area. Approximate potentiometric-surface gradients and directions are identified using geohydrologic information. The zone of contribution to Water System Canyon Spring, based on the geology and hydrogeology, appears as a wide, long strip running southeast from the spring (figure 8). It is an area upgradient from the spring, following the trend of the fault system (figure 2) and bounded by theoretical dividing lines that

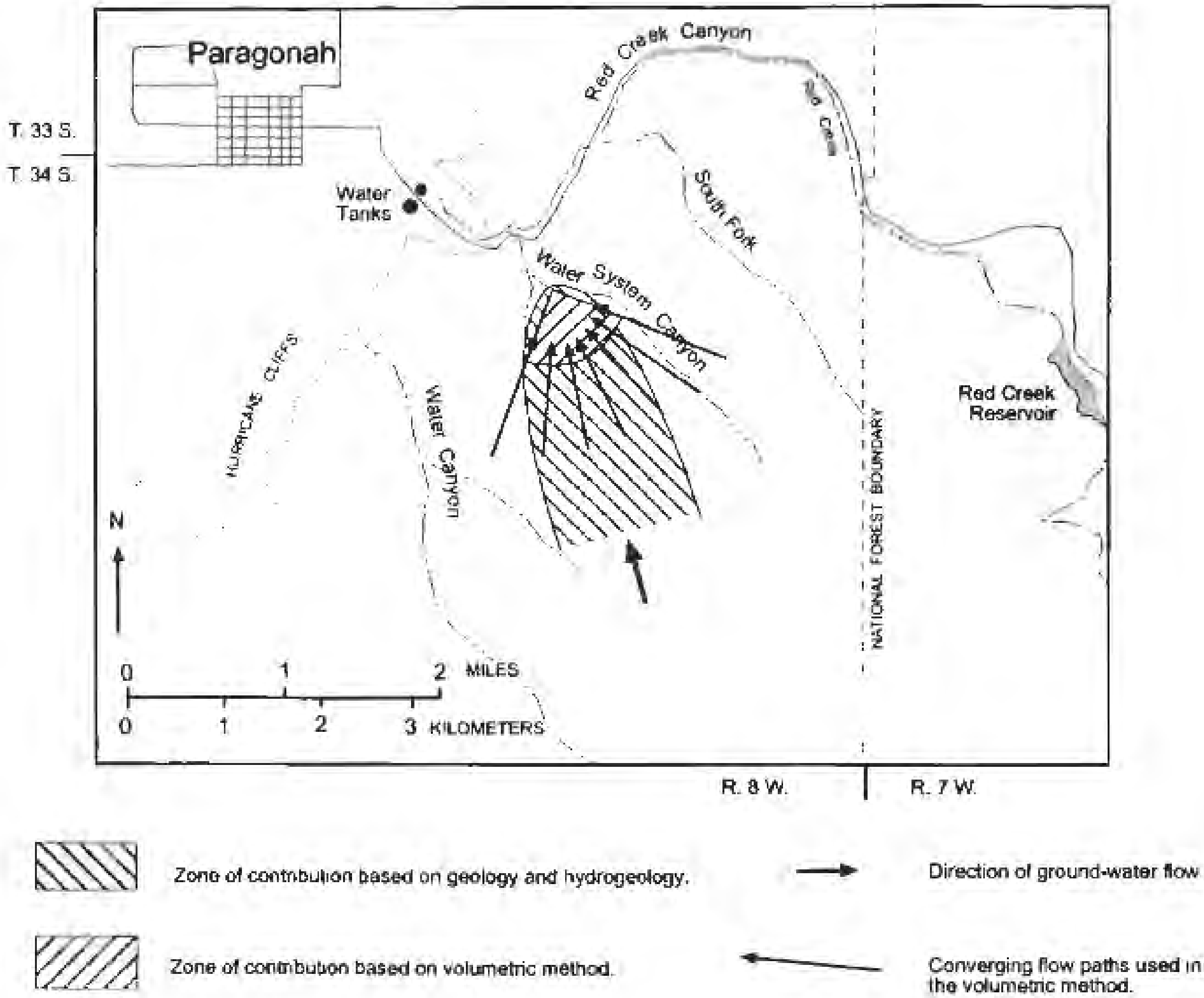


Figure 8. Zones of contribution based on geology and hydrogeology, and volumetric method.

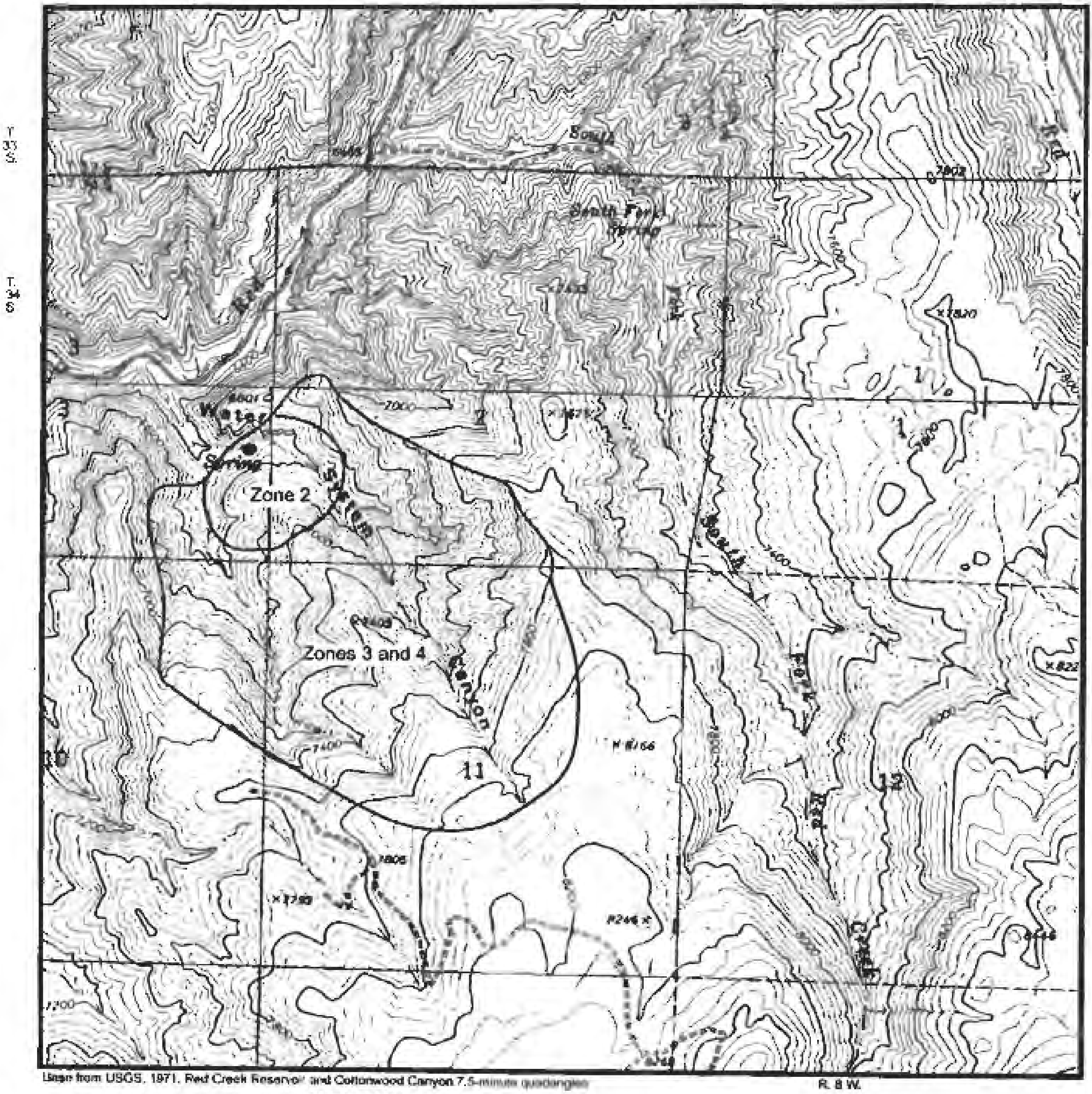
separate areas contributing to Water System Canyon spring from other areas. The dividing lines are only approximately located because boundaries of the zone are subjective and impacted by seasonal influences. The southern boundary does not exist, since no ground-water divides were defined in this study. No areas of the aquifer are considered confined or isolated from the ground surface.

Volumetric Method

Volumetric methods for estimating a zone of contribution to Water System Canyon Spring can be solved quickly; however, few assumptions in the analytical method match the aquifer. The volumetric method produces a fixed-radius travel-time zone that represents a volume of aquifer supplying water to the spring. Surface areas contributing recharge to the spring must provide an amount of water that balances with the amount of water being discharged from the spring. A volumetric method is a conservative approach because it does not account for vertical recharge. An additional advantage with this method is that few hydrologic parameters have to be estimated, and those that are, can be conservatively estimated. This results in conservative protection zones. Problems with this method include: (1) criteria for the selection of hydrologic parameters are unclear or arbitrary, (2) the method assumes radial flow to the discharging point at the spring where the potentiometric-surface gradients focus, and (3) the method neglects regional ground-water flow.

The delineation of capture zones for the spring using a volumetric method requires only estimates of hydraulic head at the spring and an average porosity of the aquifer. Ground water circulates through the entire aquifer section, but only circulation above the spring determines Water System Canyon Spring's hydraulic head. The precise geometry of the fracture and rock matrix porosity in the subsurface is unknown, but they form an interconnected network suppling water to the spring. Since the effective porosity of the aquifer is uncertain, I used 7 percent as a conservative estimate. The volumetric method results in upgradient zones of contribution, or capture zones, of 590 feet (180 m) for a 250-day period, 1,240 feet (377 m) for a 3-year period, and 2,770 feet (844 m) for a 15-year period (appendix).

The downgradient boundary of the zones of contribution to the spring is at the spring. DWSP zones 2, 3, and 4 for the spring are shown on figure 9. These zones combine the hydrogeologic investigation and the volumetric method in the sense that the volumetric method is a minimum and all zones exceed it. These potential protection zones cover only a part of the potential zone of



EXPLANATION

● Spring

Boundaries of DWSP zones 2, 3, and 4

Scale 2,000 ft

N

Figure 9. Boundaries of drinking-water-source-protection (DWSP) zones 2, 3, and 4.

contribution, but are more manageable than the capture area estimated using the method of Todd (1980). The final boundaries of all three DWSP zones extend south of the spring and exceed the distance indicated in the volumetric method, to be conservative. The boundaries extend toward the higher elevations and take into account the fault/fracture system trends. The zone 2 boundary is placed at a distance of 1,366 feet (416 m) upgradient from the spring. This was calculated using the 250-day travel time area, from the volumetric method, as a 200-foot (61 m) wide rectangular area along the fault/fracture system. The length of the area of this rectangle supplying ground water to the spring would be 1,366 feet (416 m). This method considers the discharge of the spring and the porosity of the aquifer. The maximum upgradient distance from the spring to DWSP-zone 4 boundary, orientation S. 55° E., is about 5,800 feet (1,768 m). Zone 3 is combined with zone 4 to be conservative because of the uncertainties in the system. The location of this boundary is based on the divides that separate ground water flowing to Water System Canyon Spring, South Fork Spring, the area west (downgradient) of the spring, and the top of the drainage system.

SUMMARY AND RECOMMENDATIONS

I believe that Water System Canyon Spring primarily issues from a fractured aquifer associated with a fault because: (1) it has high hardness and low TDS concentrations and the temporal variations in these parameters are small, indicating the water is not rushing through the ground-water system; however, there are some chemical indications of a deeper source of water; (2) it has a moderate discharge rate that is seasonally variable; and (3) field evidence indicates that the spring discharges at a singular point. Delineation of protection areas for Water System Canyon Spring is a complex process requiring the use of many techniques. Here, I evaluated and combined geologic and hydrogeologic methods with a volumetric method that estimated a volume of aquifer needed to supply the discharge to the spring. I used conservative values for unknown aquifer properties in determining time-related travel zones. A substantial part of the surface-drainage basin was delineated as DWSP zones 3 and 4. Protection zone 2 is smaller and more manageable. There are still uncertainties in the hydrogeologic framework and transmitting properties of the aquifer system that could affect the shape and location of the area contributing recharge to the spring. To further define the protection zone boundaries, substantial additional subsurface investigation would be needed. If additional information to better define travel times in the aquifer becomes available, I recommend the DWSP zones be redelineated as necessary.

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APPENDIX

Volumetric Method

The volumetric method produces a fixed radius of transport around a spring, based on the volume of aquifer supplying water to a spring flowing at a specific rate for a given time.

Analytical calculations require simplification of the ground-water flow system; consequently, the relatively complex aquifer system in the Water System Canyon Spring area was treated as a uniform aquifer for the analytical calculations. For a spring flowing at a rate of Q over a period of time (t_i), the total volume of discharge water is Qt_i. For a quarter cylindrical aquifer volume, supplying water to the spring, of radius r, height h, and porosity n, the total volume of water contained therein is $1/4 nh\pi r^2$.

Equating these two volumes of water and solving for r yields

$$r = \left(\frac{4Qt_i}{nh\pi}\right)^{1/2}$$

Where:

- r is radial distance (*l*)
- Q is spring discharge (l^3/t)
- π is 3.1416 (*dimensionless*)
- t_i is time of travel (*t*)
- h is hydraulic head at the spring (*l*)
- n is porosity (*dimensionless*)

Estimated hydrologic factors used in the calculation were based on the geologic and hydrogeologic evaluation of the spring. Properties used in calculations for the spring refer to average values for the entire aquifer.

Q is average spring discharge, which is 200 gal/min (0.8 m^3/min) or 38,505.6 ft^3/d (1,090 m^3/d); h is a hydraulic head in the aquifer above the spring discharge, which is 500 ft (152 m) to be conservative; n is porosity of the aquifer, which is 7 percent (0.07).

Solution:

t_i=250 days

$$r = \left(\frac{(4)(38{,}505.6\ ft^3/d)(250\ d)}{(0.07)(500\ ft)(3.1416)}\right)^{1/2}$$

r=591.2 ft

t_i=3 years (1,095 days)

r=1,238.5 ft

t_i=15 years (5,477 days)

r=2,769.8 ft