A SUMMARY OF THE GEOLOGY AND HYDROGEOLOGY OF THE CEDAR VALLEY DRAINAGE BASIN, IRON COUNTY, UTAH

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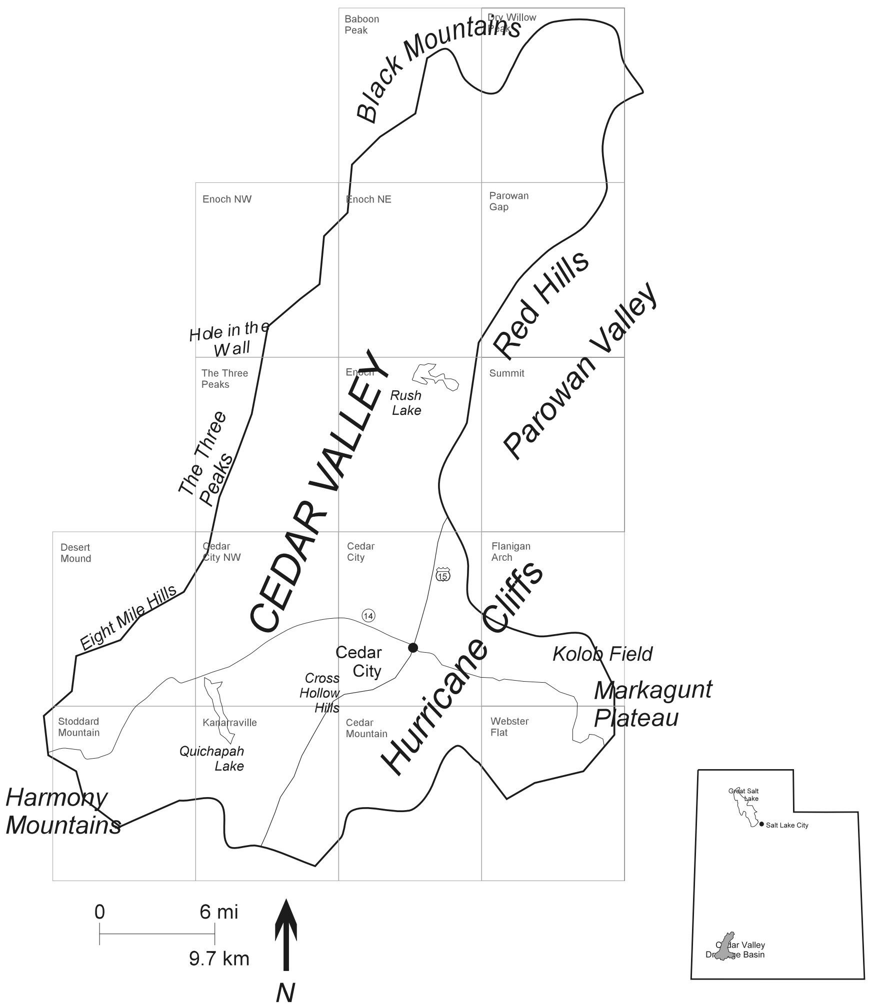

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ABSTRACT

The Cedar Valley drainage basin encompasses more than 580 square miles (1,502 km^2) in southwestern Utah. Located in the transition zone between the Basin and Range and Colorado Plateau physiographic provinces, the drainage basin includes Cedar Valley, the Hurricane Cliffs, and the western part of the Markagunt Plateau. The exposed geology of the area includes rocks of Paleozoic, Mesozoic, and Cenozoic age, with an aggregate thickness of more than 16,000 feet (4,877 m). The region witnessed an episode of calc-alkaline volcanism during the late Eocene, Oligocene, and early Miocene, and then a period of more passive volcanism beginning in the mid-Miocene. Basin-and-range extension formed Cedar Valley through large-scale normal faulting and subsequent erosion. Quaternary alluvium and volcanic deposits more than 1,000 feet thick underlie the floor of Cedar Valley. This alluvial valley fill is the principal aquifer in the basin.

Ground water in Cedar Valley exists under confined, unconfined, and perched conditions. The valley-fill aquifer is composed primarily of sand, gravel, clay, and silt, and includes many high-permeability beds that yield water up to 4,000 gallon/minute (15,100 liters/min). Perennial streams and springs are the major sources of recharge in the valley, and withdrawal of water from wells is the single largest means of ground-water discharge. Total-dissolved-solids concentrations measured in wells ranged from 158 to 2,752 mg/L (158 to 2,752 parts per million) in 1978, and the general quality of water is good. The principal ground-water contaminant identified in the Cedar Valley basin-fill is nitrate. Potential ground-water-pollution sources include septic tank soil-absorption systems, agricultural fertilizer, and sewage lagoons.

INTRODUCTION

Cedar Valley is in southwestern Utah, along the eastern margin of the Basin and Range province (figure 1). The valley is a structural depression, bordered by the Black Mountains to the north, the Markagunt Plateau to the east, and low-lying mountains and hills to the west. Parowan Valley, of similar size and geologic structure, lies directly to the northeast.

Cedar Valley is approximately 32 miles (51 km) long and its drainage basin encompasses more than 580 square miles (1,502 km^2). The floor of Cedar Valley covers 170 square miles (440 km^2), ranging from 8 miles (13 km) wide at its northern boundary to less than 1 mile (1.6 km) wide in the south. High relief along the valley's eastern and southwestern margins contrasts sharply with the flat to gently sloping morphology of the valley itself. The Hurricane Cliffs form a 3,000-foot- (914-m-) high escarpment that runs along much of Cedar Valley's southeastern boundary. Elevations in the Cedar Valley drainage basin range from 11,307 feet (3,446 m) at Brian Head to less than 5,400 feet (1,646 m) at Mud Springs Wash. Cedar Valley is underlain almost exclusively by Quaternary alluvium derived from highlands to the east and west. This

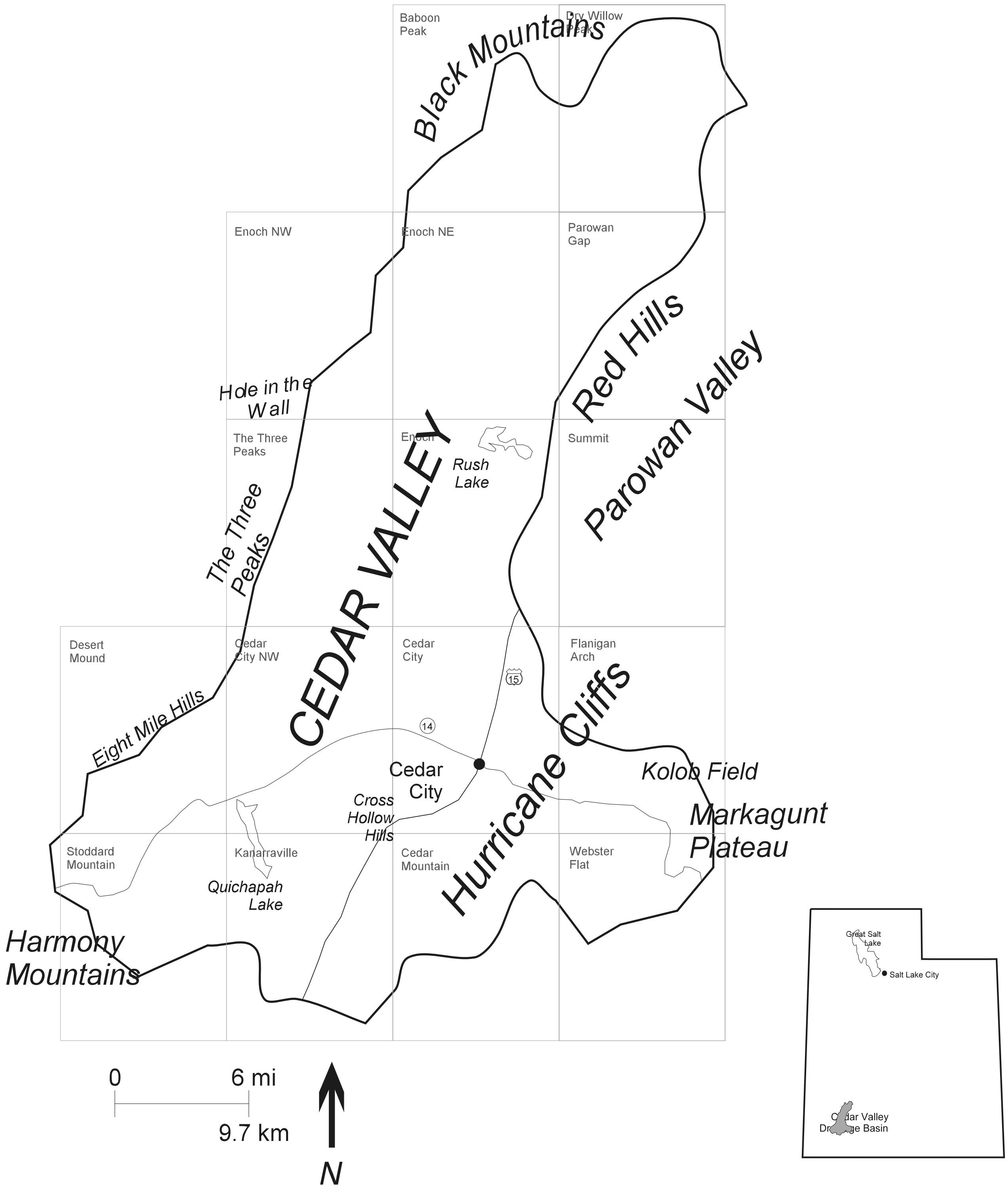

Figure 1. Cedar Valley drainage basin showing USGS 1:24,000-scale quadrangles.

alluvial valley fill is the principal aquifer in Cedar Valley.

Iron County's population increased 34 percent, from 17,349 in 1980 to 23,300 in 1995 (Utah Division of Water Rights, 1980 and 1995). According to the Utah State Water Plan (Utah Division of Water Resources, 1995) the population of the county is projected to grow another 2.5 percent annually for the next 22 years (to 2020). As the population continues to grow, so will the need for more water.

PREVIOUS INVESTIGATIONS

The geology and mineral resources of Cedar Valley have long been a topic of investigation. Early reconnaissance studies include geologic/physiographic descriptions by Gilbert (1875), Howell (1875), Powell (1879), and Dutton (1880), and at the start of the 20th century, research focused on the coal and ore deposits of the Cedar Valley region (Lee, 1907; Leith and Harder, 1908; Richardson, 1909). In the 1950s, geologists began working on more detailed studies of the region's stratigraphy and structure. Averitt (1967), Averitt and Threet (1973), Rowley (1975, 1976), Mackin and others (1976), Mackin and Rowley (1976), and Rowley and Threet (1976), produced 7.5' geologic quadrangle maps of the area, and Averitt (1962), Threet (1963), and Stewart and others (1972a,b) completed structural studies. The Hurricane fault zone and its significance as a possible boundary between the Basin and Range and Colorado Plateau physiographic provinces are discussed by Huntington and Goldthwait (1904), Mackin (1960), Averitt (1962), Hamblin (1970, 1984), Rowley and others (1978), Anderson and Mehnert (1979), Anderson (1980), and Anderson and Christenson (1989). Eppinger and others (1990) assess the mineral resources of the Cedar City $1^\circ \times 2^\circ$ quadrangle.

Ground-water conditions in Cedar Valley were first described by Thomas and Taylor (1946), with subsequent investigations by Thomas and others (1952) and Sandberg (1966). Barnett and Mayo addressed the issue of ground-water management in 1966, and at that time foresaw a potential water-resources crisis in Cedar Valley. The most recent study of ground-water conditions in both Parowan and Cedar Valley drainage basins is by Bjorklund and others (1978). Since then, ground-water data have been collected periodically for monitoring purposes by the Utah Division of Water Resources, the Utah Division of Water Quality, and the U.S. Geological Survey.

CLIMATE

Typical of western Utah's higher basins, Cedar Valley is characterized by large daily temperature variations, moderately cold winters, and warm, dry summers. Annual temperatures in the valley reach a maximum of about 100° F (38° C) and a minimum of about 0° (-18° C); the daily temperature variation is greatest in the summer when the maximum fluctuations can be as much as 40° F (22° C) (Ashcroft and others, 1992).

The Markagunt Plateau receives between 16 and 40 inches (41 and 102 cm) of snow and rain annually, but only 8 to 14 inches (20 to 36 cm) of precipitation falls in Cedar Valley (Utah

Division of Water Resources, 1995). The precipitation is usually generated by humid air masses from either the north Pacific or the Gulf of Mexico. Snow typically falls in the valley from December through March, but snowstorms can occur well into April and even May. The growing season (the number of consecutive frost-free days) is 135 days on average at the Cedar City Airport (Utah Division of Water Resources, 1995).

GEOLOGIC SETTING

The Cedar Valley drainage basin lies in the structural transition zone between the Basin and Range and Colorado Plateau physiographic provinces. The boundary between the provinces, which in southwestern Utah is commonly considered the Hurricane fault zone, shows a varying degree of definition. In the Cedar City, Cedar Mountain, and Kanarraville quadrangles, for example, the transition is fairly abrupt, but in areas to the north, changes are more gradual. According to Averitt (1962), the Hurricane fault zone is on average 3 miles (5 km) wide in the Cedar City area.

The western part of the Cedar Valley drainage basin is dominated by features commonly associated with basin-and-range extension. High-angle normal faults are common, as are large horst and graben structures. East of the Hurricane fault zone, however, upland areas show qualities typical of the Colorado Plateau. There strata generally dip to the east, and thick sections of sedimentary rocks are uplifted and sometimes deformed.

Cedar Valley is in a region that has been geologically active since Late Proterozoic time. Numerous episodes of volcanism, uplift, and deformation have affected the fundamental geologic character of the area. Faulting and uplift associated with basin-and-range extension continue in the area, with the most recent movement along the Hurricane fault zone (Anderson and Christenson, 1989). Since its initiation in the Pliocene, total vertical displacement along the Hurricane fault zone is estimated at between 1,500 and 4,000 feet (457 and 1,220 m) (Kurie, 1966; Anderson and Mehnert, 1979).

The Cedar Valley drainage basin includes rocks of Paleozoic, Mesozoic, and Cenozoic age, having an aggregate thickness of more than 16,000 feet (4,877 m) (table 1). The oldest exposed unit, the Kaibab Limestone, is found locally at the base of the Hurricane Cliffs, and is overlain by Triassic and Early Jurassic rocks. These include the red and brown sandstones, siltstones, and mudstones of the Moenkopi, Chinle, Moenave, Kayenta, and Navajo Formations. Their combined thickness is over 6,000 feet (1,829 m). The Carmel Formation, a thin-bedded fossiliferous, gray limestone of Late Jurassic age, is the next unit in the sequence. It has a maximum thickness of nearly 1,300 feet (396 m), but exhibits an east-west variability in thickness and facies types (Averitt, 1962; Hintze, 1988).

Lying unconformably above the Jurassic units are the Cretaceous Iron Springs, Dakota, Tropic, Straight Cliffs-Wahweap, and the Kaiparowits Formations. These units show a marked variation in composition and texture, and their origin is linked to the Sevier orogeny which occurred approximately 70 million years ago. This sequence, excluding the Iron Springs Formation, "crops out boldly along the crest of the Hurricane Cliffs," having a drab grayish-yellow color and a gentle dip (Averitt, 1962).

System	Geologic units		Approximate thickness (ft)
Q	Valley fill - alluvial-fan deposits, basalt flows, dune sand, lacustrine sediments, and other volcanics (undifferentiated)		0 - 3000+
Tertiary	Quartz monzonite porphyry intrusions (Granite Mountain & Three Peaks)		
Tertiary	Volcanic rocks, undifferentiated		300 - 2500
Tertiary	Claron Formation		750 - 2200
Cretaceous	Iron Springs Formation (west of Cedar City)	Kaiparowits Foramtion (east of Cedar City)	0 - 400
Cretaceous		Wahweap and Straight Cliffs Sandstones, undivided	600 - 1200
Cretaceous		Tropic Shale	700 - 800
Cretaceous	?	Dakota Formation	400 - 600
	Unconformity		
Jurassic	Carmel Formation		550 - 1300
Jurassic	Temple Cap Formation		0 - 100
Jurassic	Navajo Sandstone		1600 - 2000
Jurassic	Kayenta Formation		750 - 1600
Jurassic	Moenave Formation		350 - 500
Triassic	Chinle Formation		300 - 500
Triassic	Moenkopi Formation		1600 - 1800
P	Kaibab Formation (Harrisburg Member)		125

Table 1. Generalized stratigraphy of the Cedar Valley drainage basin with unit thicknesses. Adapted from Hintze (1988); Averitt (1962); and Bjorklund and others (1978). Q = Quaternary; P = Permian.

Tertiary rock units include the Claron Formation (also called the Wasatch Formation) and a variety of volcanic deposits. West of Cedar Valley, Tertiary igneous laccoliths of quartz monzonite are exposed at Granite Mountain and the Three Peaks. About 20 million years ago, these molten igneous bodies intruded and warped overlying Mesozoic and Cenozoic sediments, but remained buried until several million years later. During the past century these units have been mined extensively for iron and, to a lesser degree, silver, copper, and gold.

The mid-Miocene (about 15 million years ago) marks the beginning of basin-and-range extension in the western U.S., and the formation of Cedar Valley (Hintze, 1988). As high-angle normal faulting down-dropped, and to a lesser extent uplifted, large blocks, sediments were shed into the nascent basin. Over time, the basin deepened, and the amount of valley fill increased. Today, Tertiary to Quaternary alluvial sediments interbedded with lava flows and other volcanic rocks having an average thickness of about 6,300 feet (1,920 m) underlie most of Cedar Valley (Averitt, 1962; Hintze, 1988). The accumulated thickness of Quaternary valley fill is estimated to be at least 1,000 feet (Anderson and Mehnert, 1979). A gravity survey by Cook and Hardyman (1967) shows a significant gravity low for Cedar Valley.

Volcanism in Cedar Valley

Beginning in the late Eocene about 40 million years ago, southwestern Utah and southern Nevada experienced a period of widespread volcanic activity. Stratovolcanoes and caldera complexes formed throughout the region and extruded rhyolitic, dacitic, and andesitic ash-flow tuffs. In the Cedar Valley region, tuffs several hundred feet thick covered the Tertiary lowlands, while contemporaneous volcanic mudflows were common in valleys and river channels. Today, tuff crops out extensively in the Eight Mile Hills, the North Hills, and the Harmony Mountains. The mudflow deposits are found in the Black Mountains, the Eight Mile Hills, and the Hole in the Wall area. Linked to a subduction zone west of Utah, this episode of calc-alkaline volcanism lasted approximately 20 million years (Hintze, 1988), ending in the early Miocene.

More recently, intermittent basaltic volcanism associated with basin-and-range extension has produced numerous cinder cones, lava flows, and small ash deposits in the Cedar Valley drainage basin. The Red Hills on the northeast side of Cedar Valley expose a section of Quaternary lava flows several hundred feet thick. Cinder cones along the rim of the Hurricane Cliffs , such as Lone Tree Mountain, Pryor Knoll, and the Three Knolls, are the youngest volcanic features in the Cedar Valley drainage basin. These may have been active as recently as 2,000 years ago (inferred from Hamblin, 1987). Other localized outcrops of Quaternary basalt are present in the Cross Hollow Hills, in the southwestern part of Cedar City.

Mining Activity

The two principal geologic resources in the Cedar Valley drainage basin are iron ore and coal. The former has been mined intermittently in the Iron Springs district since 1849, whereas the latter was first discovered in the Kolob Field east of Cedar City (figure 1) in the 1850s. The iron, related to skarn and replacement deposits, formed during emplacement of the Granite Mountain and Three Peaks quartz monzonite laccoliths 20 million years ago (Eppinger, 1990). Magnetite and hematite deposits adjacent to these plutons have been mined in situ and in alluvial deposits. Over 250 million tons (254 million metric tons) of iron ore were produced from the Iron Springs district before mining stopped in 1995.

The coal resources of the Kolob Field are found in the upper part of the Cretaceous Tropic Shale and the lower part of the Straight Cliffs Sandstone (Averitt, 1962). Mining was initially small scale pick and shovel work, but in the 1940s, modern mechanized methods were introduced. A coal-burning electric power plant was built for Cedar City in 1947, and this became the main consumer of coal in the area. The coal varies in quality, but on average is between high volatile C bituminous and subbituminous A. The coal generally has a high ash and sulfur content, and moderate heat values (Averitt, 1962; Doelling and Graham, 1972). Commercial mining of the area's coal deposits ended in the 1960s.

SURFACE WATER

Most perennial streams in the Cedar Valley drainage basin begin in the highlands to the east. Coal Creek, the largest of these, provides nearly all the surface water used in Cedar Valley, having an average annual discharge of 23,830 acre-feet (0.029 km^3) (Bjorklund and others, 1978). Shurtz and Quichapa Creeks are two smaller perennial streams in the valley; the latter is completely diverted for irrigation purposes. Many intermittent and ephemeral streams discharge to the valley from the surrounding mountains. The surface-water inflow generated by these streams usually evaporates quickly or infiltrates into the alluvial sediments to recharge ground water.

Over time, Coal Creek has developed a large alluvial fan that divides Cedar Valley into two topographic lows occupied respectively by Rush Lake and Quichapah Lake. Both lakes play a role in recharging the valley-fill aquifer.

Cedar Valley's ground-water system is drained at three topographic gaps: two on the west side (at Iron Springs and Hole in the Wall) and one at the south end (Mud Springs Wash). Surface-water outflow through these gaps, however, is negligible (Bjorklund and others, 1978).

GROUND WATER

The valley-fill aquifer is the principal source of ground water in Cedar Valley. Ground water in this aquifer exists under perched, confined, and unconfined conditions. Water is also found in fractured-rock aquifers that both surround and underlie Cedar Valley (see Montgomery [1980] for an initial report on water exploration in the Navajo Sandstone). These bedrock aquifers, however, are poorly understood and not discussed in this summary.

The Valley-Fill Aquifer

Unconsolidated Quaternary alluvial and lacustrine deposits form the principal valley-fill aquifer system in Cedar Valley. The majority of valley fill is a combination of sand, gravel, clay, and silt deposited directly by perennial and ephemeral streams. Additionally, a small amount of valley-fill material has been reworked by lake or wind action. The thick alluvial deposits include many high-permeability beds that yield water at rates ranging from 1 to 4,000 gallons/minute (4 to 15,100 liters/min). Depth to ground water ranges from near the ground surface in the central portion of the valley to about 250 feet (76 m) below the surface along the valley margins (Bjorklund and others, 1978). "The most productive aquifers are beds of coarse, clean, well-sorted gravel and sand that absorb water readily, store it in large quantities, and yield it readily to wells" (Bjorklund and others, 1978). Silt and clay layers, while storing large quantities of water, do not readily yield it to wells. Of the 20 million acre-feet (25 km^3) of water thought to be stored in the unconsolidated deposits of the Cedar Valley aquifer system (Bjorklund and others, 1978), only 20 percent, or 4 million acre-feet (4.9 km^3), are thought to be recoverable.

Recharge

Recharge to valley-fill deposits of Cedar Valley is about 40,000 acre-feet/year (0.049 km^3/yr) (Bjorklund and others, 1978). Of the average 452,000 acre-feet (0.558 km^3) of precipitation that falls on the drainage basin annually, little reaches ground-water reservoirs due to evaporation and transpiration. Streams are a major source of recharge in the valley, and usually flow from the mountains into highly permeable alluvial-fan deposits. Bjorklund and others (1978) found ground-water mounds underlying several alluvial fans which show water-table slopes radiating away from the fan axes. Subsurface inflow through adjacent mountain blocks may contribute a relatively small amount of recharge to Cedar Valley aquifers. Bjorklund and others (1978) suggest the greatest amount of inflow would probably be "in places where the limestone and conglomerate of the Tertiary Wasatch Formation, Tertiary and Quaternary volcanic rocks, and the Mesozoic Navajo Sandstone are in contact with Quaternary valley fill."

Occurrence

Both confined and unconfined ground water exists in the unconsolidated fill of Cedar Valley. Under confined conditions, ground water is trapped beneath an impermeable layer "retarding the upward movement of water toward the land surface and allowing hydrostatic pressure to build up in the aquifer" (Bjorklund and others, 1978). In Cedar Valley the confining layers are thickest in the middle of the valley and thin toward the valley margins. Furthermore, the water-bearing beds are often not completely confined as water tends to seep (or leak) upward toward the ground surface. The transition from confined aquifer zones to unconfined zones is usually gradual (Bjorklund and others, 1978). Local perched water bodies are also common in the valley fill. "They develop above the main ground-water reservoir in localities where beds of clay or other materials of low permeability intercept water percolating downward, or where water levels in lower aquifers are lowered by the withdrawal of water and the upper aquifers are less affected" (Bjorklund and others, 1978).

Permeability (a measure of the amount, size, and interconnection of void spaces) is locally high in the unconsolidated valley fill of Cedar Valley. Generally, the larger the grain size and better the sorting in deposits, the higher the permeability and transmissivity (a measure of the amount of water that can be transmitted horizontally through a unit width of an aquifer or confining bed under a unit hydraulic gradient). In Cedar Valley, the highest transmissivity is in the Coal Creek alluvial fan, about 3 miles north of Cedar City, where values are as high as 52,000 ft^2/day (4,831 m^2/day) (Bjorklund and others, 1978). The area of lowest transmissivity is likely between Rush Lake and the Black Mountains, although this is speculative because few wells have been drilled in that area.

Discharge

The average annual discharge in Cedar Valley is about 44,000 acre-ft (.054 km^3) (Bjorklund and others, 1978). Springs and evapotranspiration account for some of this (fewer than 1,000 acre-feet (1,233,000 m^3) of discharge [Bjorklund and others, 1978]), but withdrawal of water from wells is currently the single-largest means of ground-water discharge (Utah Division of Water Resources, 1997). In 1975, almost 43,000 acre-feet (52,176,000 m^3) of ground water were pumped for irrigation, municipal supply, domestic, and stock use (Bjorklund and others, 1978). In more recent years, the annual pumpage has decreased to about 35,000 acre-feet (41,922,000 m^3) (Utah Division of Water Resources, 1997).

Evapotranspiration by phreatophytes (plants that obtain water in the zone of saturation and characteristically maintain deep root systems) and evaporation from the playas of Quichapa and Rush Lakes also play a small role in Cedar Valley's total ground-water budget; withdrawal is only about 2,000 acre-feet (2,466,000 m^3) annually (Bjorklund and others, 1978).

Water Quality

Total-dissolved-solids (TDS) concentrations of Cedar Valley ground water ranged from 158 to 2,752 mg/L (158 - 2,752 parts per million) in 1978 (Bjorklund and others). The source of dissolved material is often the rocks through which the water flows. Gypsum, for example, contributes significant quantities of sodium and calcium to ground water. In Cedar Valley, ground water is generally classified as either a calcium-bicarbonate type or a magnesium-sulfate type, and is suitable for most uses. Bjorklund and others (1978) did note, however, that the "concentration of dissolved solids tends to increase with time in areas where large quantities of water are pumped for irrigation."

The valley-fill aquifer is the principal source of drinking water for residents of Cedar Valley. Potential ground-water-pollution sources include underground storage tanks, sewage lagoons, septic tank soil-absorption systems, and agricultural fertilizer. Domestic waste water in rural areas and some subdivisions is disposed of in on-site individual waste-water disposal systems. Residential development, agriculture, and manufacturing are all taking place on the basin-fill aquifer.

The principal ground-water contaminant identified in the Cedar Valley basin-fill aquifer is nitrate. Concentrations in water wells in 1979 ranged from less than 0.06 mg/L to 57.4 mg/L (0.06 - 57.4 parts per million) (Joe Melling, Cedar City Manager, formerly with the Southwest Utah Public Health Department, written communication, 1979). Nineteen of these wells exceeded 10 mg/L (10 parts per million) (current Utah ground-water-quality standards permits a maximum nitrate concentration of 10 mg/L). The high-nitrate wells are distributed throughout Cedar Valley, rather than concentrated in a single area of high-nitrate concentration. High-nitrate wells are more common near the Hurricane fault on the east side of the valley.

SUMMARY

The Cedar Valley drainage basin exists in the structural transition zone between the Basin and Range and Colorado Plateau provinces. During the past 200 million years, the region has been affected by several periods of volcanism and tectonic deformation. Since the late Paleozoic more than 16,000 feet (4,877 m) of sediments have accumulated in the area. Exposed units include sandstones, siltstones, mudstones, volcanic deposits, and, more recently, alluvial-fan deposits and other valley-fill material. During the past 10 million years, basin-and-range extension has played an important role in the formation and subsequent modification of Cedar Valley.

The Cedar Valley drainage basin receives between 8 and 40 inches (20 and 102 cm) of precipitation annually. Most of this falls as snow in the highlands, and if not lost to evaporation or transpiration, recharges the valley-fill aquifer of Cedar Valley. Over 1,000 feet thick, the unconsolidated valley-fill deposits store an estimated 4 million acre-feet (4.9 km^3) of recoverable water. The ground water is under both unconfined and confined conditions.

The annual well pumpage in Cedar Valley was about 34,000 acre-feet (41,922,000 m^3) in 1994, or more than 75 percent of the total annual discharge for the valley. Other less significant sources of discharge include valley springs, evapotranspiration by phreatophytes, and evaporation from the playas of Quichapa and Rush Lakes.

The general quality of Cedar Valley's ground water is good. Total-dissolved-solids concentrations range from 158 to 2,752 mg/L (158-2,752 ppm). The principal identified ground-water contaminate is nitrate. Potential ground-water-pollution sources include septic tank soil-absorption systems, agricultural fertilizer, and sewage lagoons.

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