GEOHYDROLOGY AND NUMERICAL SIMULATION OF GROUND-WATER FLOW IN THE CENTRAL VIRGIN RIVER BASIN OF IRON AND WASHINGTON COUNTIES, UTAH

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ABSTRACT

Because rapid growth of communities in Washington and Iron Counties, Utah, is expected to cause an increase in the future demand for water resources, a hydrologic investigation was done to better understand ground-water resources within the central Virgin River basin. This study focused on two of the principal ground-water reservoirs within the basin: the upper Ash Creek basin ground-water system and the Navajo and Kayenta aquifer system.

The ground-water system of the upper Ash Creek drainage basin consists of three aquifers: the uppermost Quaternary basin-fill aquifer, the Tertiary alluvial-fan aquifer, and the Tertiary Pine Valley monzonite aquifer. These aquifers are naturally bounded by the Hurricane Fault and by drainage divides. On the basis of measurements, estimates, and numerical simulations of reasonable values for all inflow and outflow components, total water moving through the upper Ash Creek drainage basin ground-water system is estimated to be about 14,000 acre-feet per year. Recharge to the upper Ash Creek drainage basin ground-water system is mostly from infiltration of precipitation and seepage from ephemeral and perennial streams. The primary source of discharge is assumed to be evapotranspiration; however, subsurface discharge near Ash Creek Reservoir also may be important.

The character of two of the hydrologic boundaries of the upper Ash Creek drainage basin ground-water system is speculative. The eastern boundary provided by the Hurricane Fault is assumed to be a no-flow boundary, and a substantial part of the ground-water discharge from the system is assumed to be subsurface outflow beneath Ash Creek Reservoir along the southern boundary. However, these assumptions might be incorrect because alternative numerical simulations that used different boundary conditions also proved to be feasible. The hydrogeologic character of the aquifers is uncertain because of limited data. Differences in well yield indicate that there is considerable variability in the transmissivity of the basin-fill aquifer. Field data also indicate that the basin-fill aquifer is more transmissive than the underlying alluvial-fan aquifer. Data from the Pine Valley monzonite aquifer indicate that its transmissivity may be highly variable and that it is strongly influenced by the connection of fractures.

The Navajo and Kayenta aquifers provide most of the potable water to the municipalities of Washington County. Because of large outcrop exposures, uniform grain size, and large stratigraphic thickness, these formations are able to receive and store large amounts of water. In addition, structural forces have resulted in extensive fracture zones that enhance ground-water recharge and movement within these aquifers. Aquifer testing of the Navajo aquifer indicates that horizontal hydraulic-conductivity values range from 0.2 to 32 feet per day at different locations and may be primarily dependent on the extent of fracturing. Limited data indicate that the Kayenta aquifer generally is less transmissive than the Navajo aquifer. The aquifers are bounded to the south and west by the erosional extent of the formations and to the east by the Hurricane Fault, which completely offsets these formations and is assumed to be a lateral

no-flow boundary. Like the Hurricane Fault, the Gunlock Fault is assumed to be a lateral no-flow boundary that divides the Navajo and Kayenta aquifers within the study area into two parts: the main part, between the Hurricane and Gunlock Faults; and the Gunlock part, west of the Gunlock Fault.

Generally, the water in the Navajo and Kayenta aquifers contains few dissolved minerals. However, two distinct areas contain water with dissolved-solids concentrations greater than 500 milligrams per liter: a larger area north of the city of St. George and a smaller area a few miles west of the town of Hurricane. Mass-balance calculations indicate that in the higher-dissolved-solids area north of St. George, as much as 2.7 cubic feet per second may be entering the aquifer from underlying formations. For the area west of Hurricane, as much as 1.5 cubic feet per second may be entering the aquifer from underlying formations.

On the basis of measurements, estimates, and numerical simulations, total water moving through the Navajo and Kayenta aquifers is estimated to be about 25,000 acre-feet per year for the main part and 5,000 acre-feet per year for the Gunlock part. The primary source of recharge is assumed to be infiltration of precipitation in the main part and seepage from the Santa Clara River in the Gunlock part. The primary source of discharge is assumed to be well discharge for both the main and Gunlock parts of the aquifers. Numerical simulations indicate that faults with major offset, such as the Washington Hollow Fault and an unnamed fault near Anderson Junction, may impede horizontal ground-water flow. Also, increased horizontal hydraulic conductivity along the orientation of predominant surface fracturing may be an important factor in regional ground-water flow. Simulations with increased north-south hydraulic conductivity substantially improved the match to measured water levels in the central area of the model between Snow Canyon and Mill Creek. Numerical simulation of the Gunlock part, using aquifer properties determined for the city of St. George municipal well field, resulted in a reasonable representation of regional water levels and estimated seepage from and to the Santa Clara River. To further quantify the Gunlock part of the Navajo and Kayenta aquifers, a better understanding of ground-water flow at the Gunlock Fault is needed.

INTRODUCTION

Ground-water resources in the central Virgin River basin of Washington and Iron Counties, Utah, were studied at the request of the State of Utah Division of Water Rights and the Washington County Water Conservancy District. The central Virgin River basin study area (fig. 1) encompasses the part of the Virgin River drainage west of the Hurricane Fault up to and including the Santa Clara River. Although the study area is contiguous with respect to surface water flow, two distinct types of aquifer systems provide most of the available ground water in the region: alluvial-basin sediments and consolidated-rock formations. The main alluvial-basin aquifer is located in the upper Ash Creek drainage basin. The main consolidated-rock aquifers in the study area are within the Navajo Sandstone and the Kayenta Formation. Alluvial deposits along the Virgin River Valley and the Santa Clara Valley also yield substantial amounts of ground water to wells but generally do not provide water of sufficient quality for potable uses. The primary objective of this study is to investigate the amount and quality of ground water within the upper Ash Creek drainage basin and the Navajo Sandstone and Kayenta Formation.

The population of southwestern Utah is increasing rapidly. In 1980 the population of Washington County was 26,000, whereas in 1997, the population was estimated to be 76,350 (Utah State Data Center, written commun., 1998) and is expected to continue increasing in the future. This growth is driving the need for further development of existing water resources and the search for additional potential ground-water sources. To meet the growing demand for water, the Utah State Department of Natural Resources, Division of Water Rights, and the Washington County Water Conservancy District provided funding for the U.S. Geological Survey (USGS) to conduct a hydrogeologic study to determine the amount and quality of ground water moving through the study area and to assess the hydrologic character of the aquifers. The information will be used to assess the potential effects of increased development on ground-water resources and to aid in the search for additional ground-water reserves.

A better understanding of the ground-water systems is critical for the further development of ground-

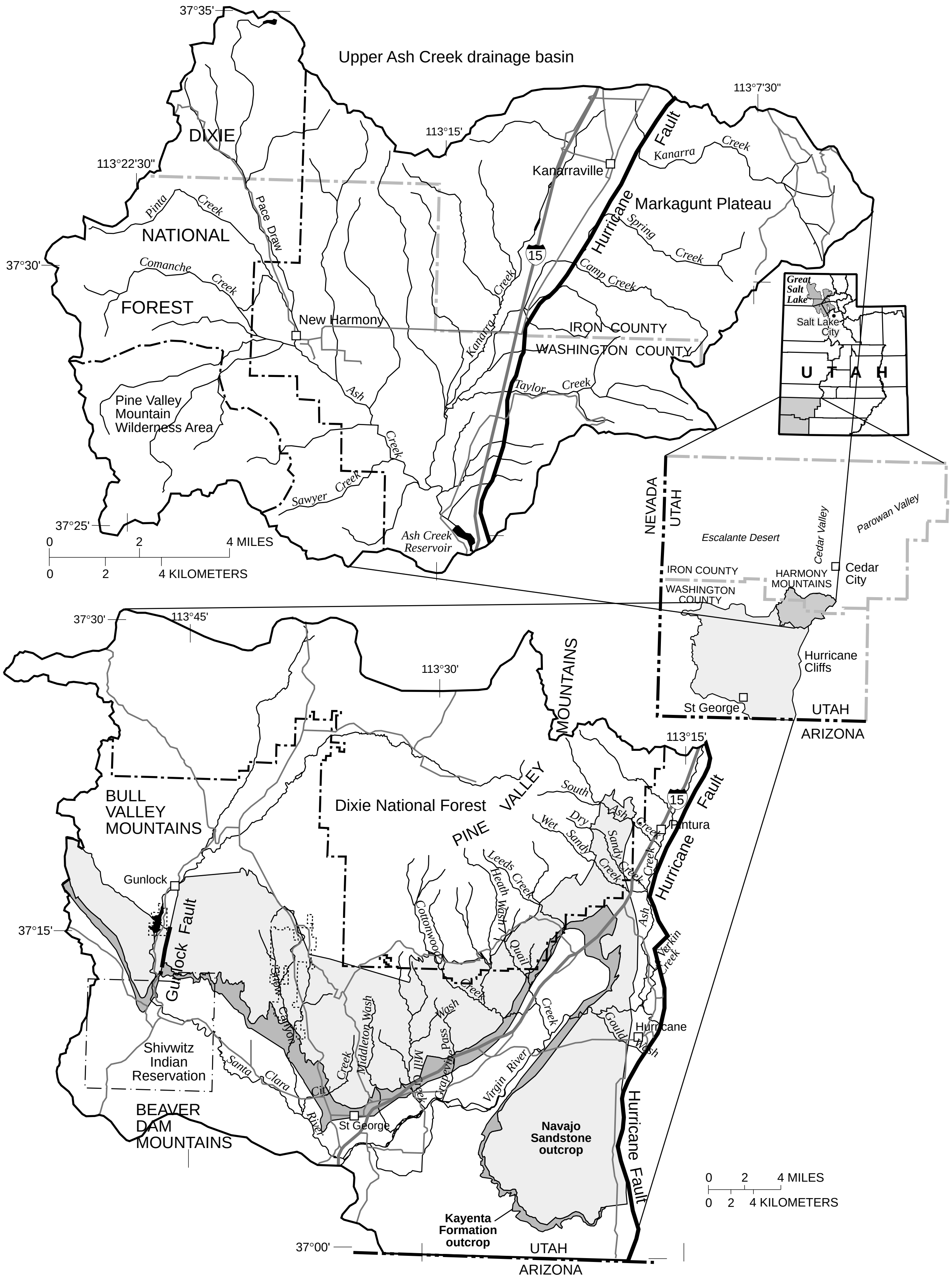

Figure 1. Location of the upper Ash Creek drainage basin and the Navajo Sandstone and Kayenta Formation outcrops within the central Virgin River basin study area, Utah.

water resources, and the scarcity of hydrologic information is a problem. The small amount of hydrologic information available for the upper Ash Creek drainage basin results in a hydrologic conceptualization that is irresolute. Existing wells, which mostly tap the basin-fill deposits, vary widely in yield, presumably because of the variability in the hydraulic conductivity of the saturated deposits. A group of more recently drilled wells on the southwest side of the drainage basin is finished in igneous rocks commonly exposed in the Pine Valley Mountains. A few of these wells can be pumped at several thousand gal/min with only a small decline in water level. Other wells finished in the same igneous rocks have low yields. These differences are thought to be caused by heterogeneity and anisotropy from the varying density and connectivity of fractures. Both properties are difficult to quantify and to map.

Ground water from the Navajo Sandstone and the Kayenta Formation has been extensively developed in certain areas along the formation outcrops; however, hydrologic data are not available for many other parts of the outcrops, or where the formations are buried in the north part of the study area. Also, fracturing within these formations, which is extremely variable throughout the study area and strongly affects the movement of ground water, is not well defined. Therefore, the conceptualization of how the hydrologic system functions is not well understood.

Development of an accurate ground-water budget is needed to improve the understanding of the ground-water systems. Ground-water recharge from precipitation, from infiltration beneath streams, from irrigated fields, and possibly from overlying or underlying formations, make up the inflow components of a ground-water budget. However, these components are not well understood or quantified for the upper Ash Creek drainage basin ground-water system for the aquifers of the Navajo Sandstone and Kayenta Formation. Some components of ground-water discharge, such as well pumpage, spring discharge, and discharge to streams can be fairly accurately quantified. However, other discharge components, including evapotranspiration and subsurface outflow to adjacent aquifers, cannot be accurately determined.

Description of the Study Area

The central Virgin River basin study area is in the southwestern corner of Utah, generally west of the Hurricane Fault (fig. 1). The area encompasses about 1,070 mi^2 along the transition between the complexly faulted and folded formations of the Basin and Range Physiographic Province and the gently dipping formations of the Colorado Plateau Physiographic Province, as described by Fenneman (1931). The study area is defined on the west and north sides by the drainage divide between the Virgin and Santa Clara River basins and adjacent drainage basins along the Beaver Dam Mountains, Bull Valley Mountains, Pine Valley Mountains, and Harmony Mountains; the boundary on the east is generally the Hurricane Cliffs, except for a small part of the Markagunt Plateau farther east; the boundary on the south is the Utah-Arizona State line (Cordova and others, 1972). Most of the study area is characterized by sedimentary formations of Mesozoic age, igneous rocks of Tertiary age, and alluvial and basalt-flow deposits of Quaternary age (pl. 1).

The 134 mi^2 upper Ash Creek drainage basin is defined as the surface-water drainage basin that drains into Ash Creek Reservoir, which is located 21 mi south of Cedar City and just west of Interstate 15 (fig. 1). The northern study area boundary divides the internal drainage of the Great Basin from the Virgin River part of the Colorado River drainage basin. The position of the surface-water divide is about 1.5 mi north of Kanarraville, Utah. The ground-water divide in the unconsolidated alluvium, which is roughly coincident with the surface-water divide, can shift slightly with variations in the location and amount of both recharge and pumpage. Topographically, the upper Ash Creek drainage basin consists of gently sloping lowland valley areas that are nearly encircled by the Harmony Mountains to the north, the Pine Valley Mountains to the southwest, and the Markagunt Plateau to the east. The Hurricane Fault zone trends north-northeast near the eastern edge of the upper Ash Creek basin, just east of Interstate 15. A narrow but thick deposit of unconsolidated alluvium has accumulated along the trace of the Hurricane Fault and connects the upper Ash Creek drainage basin northward with the southern end of Cedar Valley (pl. 1).

Within the study area, the Navajo Sandstone has an outcrop area of about 220 mi^2. The Kayenta Formation has an outcrop area of about 35 mi^2. Both formations are buried toward the north by overlying formations for an additional 500 mi^2 within the study area. The formations are absent in the southern part of the study area because of erosion. The outcrops extend from the Hurricane Fault on the east to the Bull Valley Mountains on the west (fig. 1) and vary in altitude from about 2,900 ft to 5,300 ft. In the western part of the study area is the Gunlock Fault, across which the Navajo Sandstone and Kayenta Formation are verti-