THE RELATION OF GEOLOGY TO HYDROLOGY IN THE SEGI MESAS AREA, UTAH AND ARIZONA

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INTRODUCTION

The geohydrology of the Segi Mesas area of the Navajo Indian Reservation and the Red Rock Plateau from Organ Rock anticline on the east to Navajo Mountain on the west, is controlled by the San Juan and Colorado Rivers (Fig. 1). This rugged and picturesque country of about 1,000 square miles varies in altitude mostly between 3,300 and 7,000 feet above sea level and consists of "***a series of mesas piled on mesas, surrounded and intersected by chasms attaining maximum depths exceeding 1,200 feet***" (Gregory, 1916, p. 48). All the streams in this area drain into the San Juan and the Colorado Rivers. The larger tributary drainage basins of the San Juan River—such as Copper, Nakai, and Piute Creeks—are 20 to 30 miles long and 5 to 6 miles wide. Other tributaries are Deep, Desha, Bald Rock, and Nasja Canyons. The streams of these canyons have steep gradients—75 to 200 feet per mile. Gradients of all tributaries are steep in stretches where they flow on resistant sandstone beds. In places the tributaries are enclosed by nearly vertical narrow walls which form an inner gorge cut below the general level of the canyon bottoms.

The Segi Mesas area lies on the western flank of the broad, northward-trending Monument upwarp, which is the dominating structure in the central part of the Colorado Plateaus province. From the upwarp the strata dip gently westward across the area to the confluence of the Colorado and San Juan Rivers. The regional dip is slightly steeper than the gradient of the San Juan River. Numerous folds—Organ Rock, Balanced Rock, and Beaver Creek anticlines and related monoclines and synclines—and the structural dome of Navajo Mountain, a probable laccolith, break up and modify the western part of the upwarp (Fig. 1).

The general east-west trend of San Juan Canyon suggests that it was formed from a superimposed drainage that had little relation to the tilted rocks of Monument upwarp (Baker, 1936, p. 80). During the course of downcutting, however, the San Juan River adjusted to some of the folds, as indicated by the Great Bend which lies in a northwest-plunging synclinal area between the Balanced Rock anticline and the Circle Cliffs anticline and the sharp bend of the river formed immediately upstream from the Balanced Rock anticline at the mouth of Nakai Creek (Fig. 1). The San Juan River crosses most of the anticlines through structural saddles, which form local lows on the anticlinal crests.

The north-flowing tributaries of the San Juan have adjusted to the geologic structure, especially in their lower reaches. Thus, the lower part of Copper Creek is in the Copper-Henry syncline, Nakai Creek is in the Nakai syncline, and Piute Creek is in a low structural area between the Balanced Rock and Beaver Creek anticlines. Except for Castle Creek and Wilson Canyon, the south-flowing tributaries from Red Rock Plateau are smaller and show less adjustment to the structure. The tributary streams flowing from the Navajo Mountain dome have developed a radial drainage pattern.

The major aquifers in the area are the Navajo and Wingate sandstones of the Glen Canyon group and the Shinarump member of the Chinle formation. The bulk of the Chinle formation is an impermeable shaly sequence about 800 feet thick which lies between the Wingate sandstone and Shinarump member. The Moenkopi formation, composed mostly of siltstone, forms the confining layer below the Shinarump member. Minor aquifers, not discussed in this report but which are local sources of ground water, include formations of Late Jurassic age on Navajo Mountain, some members of the Cutler formation of Permian age in the Nakai-Copper Canyon area, and the Quaternary alluvium, which is present along the San Juan and Colorado Rivers and along parts of the tributary streams.

The basic data contained in this report were obtained from a ground-water study made by the Ground Water Branch of the U. S. Geological Survey, Navajo Project (1950-55), and from a geologic investigation made by the Museum of Northern Arizona, Glen Canyon Project (1957-60).

NAVAJO SANDSTONE-WINGATE SANDSTONE AQUIFER SYSTEM

The pale-reddish-brown to grayish-orange-pink Navajo and Wingate sandstones are the principal aquifers. Ground water issues from the base of both units, forming prominent spring horizons in the canyon and mesa country. These units are composed mainly of well-sorted, very fine to fine-grained quartz sand. They are very thick bedded and contain large-scale crossbeds which can be traced laterally for several hundred feet. The Kayenta formation lies between the Navajo and Wingate and is composed of tightly cemented sandstone and silty sandstone which generally retards ground-water movement. These three formations form the cap of the Segi Mesas and Red Rock Plateau. The Navajo sandstone, ranging in thickness from 500 to 1, 000 feet, caps much of Rainbow and Red Rock Plateaus and the region south of the Segi Mesas. The Navajo has been removed by erosion from most of the Segi Mesas, and the Kayenta formation crops out on the summit areas. The Wingate sandstone, about 300 feet thick, is eroded into vertical cliffs below the Kayenta caprock and rises above steep slopes cut from the Chinle formation.

The movement of ground water in the Navajo and Wingate sandstones radiates from the Navajo Mountain dome to the Colorado River, San Juan River, and Piute Creek. The eastward movement from Navajo Mountain is restricted partly by the Beaver Creek anticline. A small amount of ground water moves northward along Piute Mesa syncline and discharges at the north end of Piute Mesa. North of the San Juan River on Red Rock Plateau ground water, following the regional dip of the Monument upwarp, moves generally westward and northwestward to the Colorado River. However, Balanced Rock and Beaver Creek anticlines interrupt the westward movement and divert some of the water southward to the San Juan River along Copper-Henry and Rapid synclines. The runoff from a short reach of a perennial stream in Wilson Canyon occupying Rapid syncline was estimated to be 50 gpm (gallons per minute) in June 1958. Castle Creek in Copper Canyon syncline is intermittent and has a few short perennial reaches along its course.

In much of the Segi Mesas area, downward interformational movement

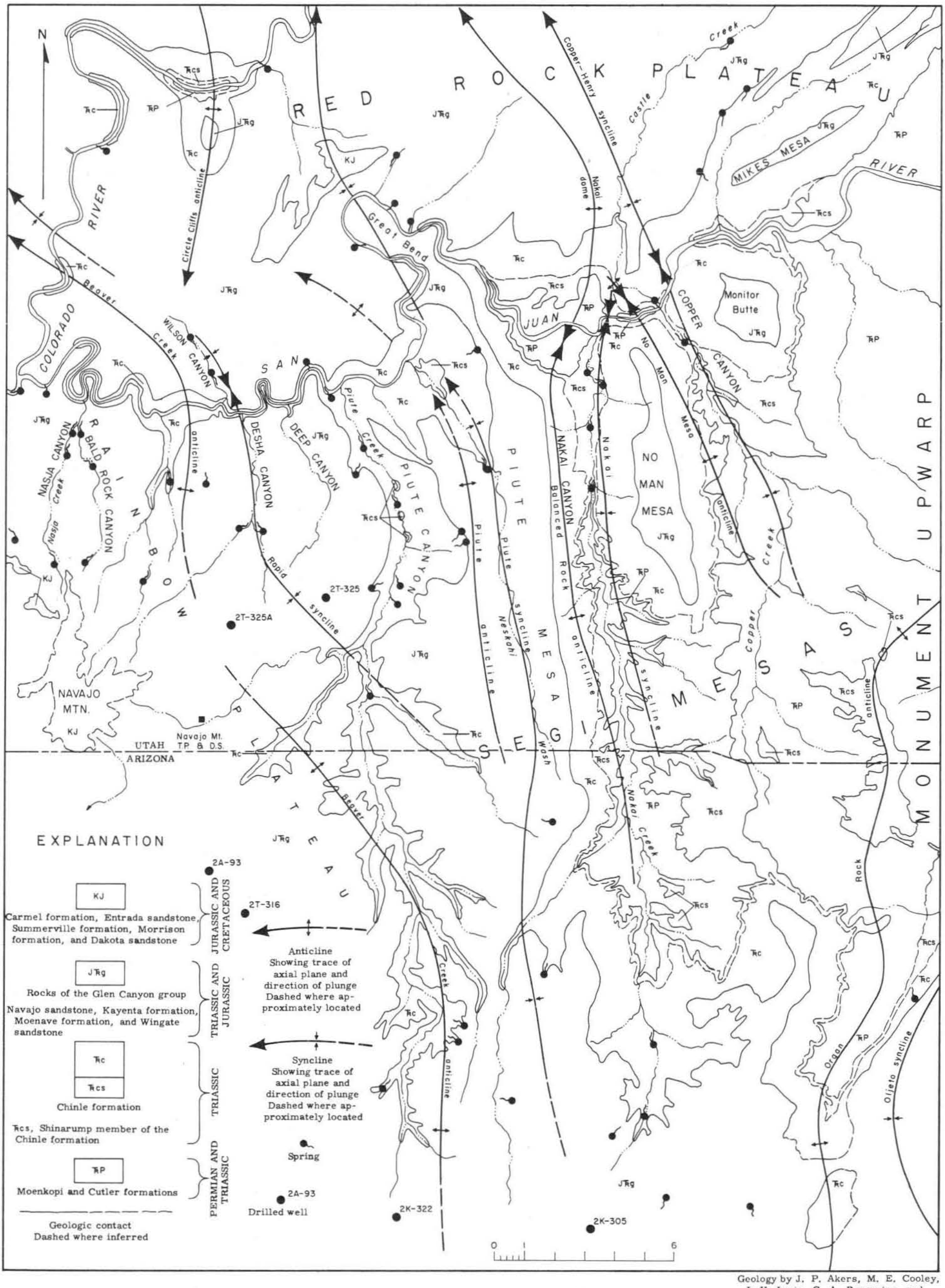

Figure 1.--Geologic map of the Segi Mesas area, Utah and Arizona.

Geology by J. P. Akers, M. E. Cooley, J. H. Irwin, C. A. Repenning, and P. R. Stevens.

of water from the Navajo to the Wingate is aided by prominent fracturing and jointing and by sandstone zones in the Kayenta formation. Therefore, the Navajo, Kayenta, and Wingate form a multiple aquifer system. However, the aquifer system is imperfectly developed because the permeability of the Kayenta formation is comparatively low.

This interformational movement is shown by springs issuing from the Wingate sandstone in Piute, Deep, Desha, and Nasja Canyons and by wells on Rainbow Plateau where the aquifer is overlain by younger formations and cannot be recharged directly from precipitation. The best examples are a Wingate sandstone spring in Desha Canyon that yields more than 100 gpm and the perennial reach of Nasja Creek, supplied by springs from the Wingate, which discharges about 50 gpm into the San Juan River. The only recharge to all these springs is from precipitation on exposures of the Navajo sandstone or Kayenta formation and downward movement into the Wingate sandstone. About 8 miles southeast of Navajo Mountain, the Navajo sandstone is at the surface, and wells 2A-93 and 2T-316 yield small amounts of water withdrawn almost entirely from the Wingate sandstone. The static water levels in these wells are below the upper contact of the Wingate sandstone. The Kayenta formation was reported dry, and the Navajo sandstone was dry or contained only a show of water. However, the Navajo sandstone south of the Segi Mesas area yields water to wells 2K-305 and 2K-322.

Faults and small folds divert more ground water along structural trends in the Wingate sandstone than in the Navajo sandstone. Springs issue from the Wingate from small northeast-trending faults along the borders of Rainbow Plateau and Piute Mesa. East of Navajo Mountain, on the northeast limb of Beaver Creek anticline, well 2T-325A was drilled to the base of the Wingate sandstone and was dry. However, 3 miles east, well 2T-325, drilled to the Wingate sandstone on the flank of Rapid syncline, yields sufficient water for stock and domestic use.

SHINARUMP MEMBER AQUIFER SYSTEM

The Shinarump member of the Chinle formation in the Segi Mesas area is chiefly a light-gray and grayish-orange-pink sandstone and conglomeratic sandstone which is mottled in part by splotches of pale brown and pale reddish purple. It is composed of subrounded to subangular fine- to coarse-grained clear quartz sand. As a whole, the sand is poorly sorted, but sand composing some of the beds is well sorted or fair sorted. The beds containing the better sorted sand are composed principally of fine-grained sand and contain low-angle crossbeds. The member consists of a maze of channel-type deposits, and medium- and large-scale crossbeds are displayed in all exposures. In most places the Shinarump is firmly cemented by calcareous and siliceous materials. In much of the area near the San Juan River the Shinarump member is more than 150 feet thick, and in Nakai Canyon it is between 180 and 200 feet thick. The member thins eastward and southward from the mouth of Nakai Canyon and is less than 50 feet thick at Monitor Butte and in the upper reaches of Nakai and Copper Canyons. The basal contact is a channeled erosion surface which has a local relief of at least 50 feet.

The Shinarump member of the Chinle formation is exposed on flanking platforms around the Segi Mesas and forms the floor in the lower part of Piute, Nakai, and Copper Canyons (Fig. 1). It outlines, as a great arch, the Balanced

Rock anticline along the San Juan River. This anticline separates ground-water movement within the Shinarump into two areas. East of the anticline, movement is principally to the Nakai syncline and subordinately to the Copper-Henry syncline. This area receives recharge to the Shinarump from the east side of the Balanced Rock anticline and from the gentle western limb of the Organ Rock anticline. Ground water in the trough of Nakai syncline moves northward, where it is discharged to the San Juan River. West of Balanced Rock anticline, recharge can occur only in exposures of the Shinarump in the upper part of Nakai Canyon. Water moves westward and northwestward toward Rapid syncline and discharges to Piute Creek and probably into the San Juan River at the mouth of Neskahi Wash.

North of the San Juan River, the Shinarump is recharged locally by precipitation or by some of the ephemeral south-flowing tributaries of the San Juan River. The pinchout north of Monitor Butte precludes any appreciable recharge to, or regional ground-water movement within, the member in Red Rock Plateau (Fig. 1).

North of the San Juan River, about half a mile upstream from the mouth of Nakai Creek, water levels were measured in a series of test holes across a low-angle reverse fault (Fig. 2). The fault is exposed in the gorge of the San Juan River, but no surface expression of the fault is visible elsewhere. However, water levels in test holes drilled on the upthrown block are between 115 and 154 feet below the land surface; water levels on the downthrown side are deeper—between 190 and 198 feet below the land surface. The difference in the water level across the fault may indicate a loss of water along this structural feature to the San Juan River.

From the Shinarump member, the measurable discharge from 12 springs in the Segi Mesas area totals only 22 gpm, although the wetted area indicates additional discharge. All the springs and seeps in the Shinarump are associated with vertical joints and bedding planes. One spring in Copper Canyon issues from the base of a small channel which is in the upper part of the member and which is outlined in profile on the canyon wall. A few thin layers of greenish-gray mudstone are present at the bottom of the channel and form a local barrier to the movement of water.

HYDROLOGY OF NAKAI CREEK

The ground-water hydrology of the narrow canyons between the Segi Mesas has not been studied because of insufficient data. Fortunately, however, about 70 uranium test holes were drilled near the confluence of Nakai Creek with the San Juan River during the period 1954-57 (Fig. 2). The 5-inch-diameter test holes were drilled to the contact of the Shinarump member with the underlying Moenkopi formation, or to a maximum depth of about 200 feet. The area included is about 1-1/2 miles long, parallel to the creek, and 4/5 mile wide. Nakai Creek flows in a shallow channel that was cut on the Shinarump member in the southern border of the area (Fig. 2). Downstream, the creek has carved a narrow gorge which is deepest at its mouth. The gorge has been partly filled, and Nakai Creek within a mile of the San Juan River flows on a bed of sandy alluvium.

Almost all the test holes contained water and have water levels ranging from 45 feet below the land surface, a mile south of the San Juan River, to about

175 feet adjacent to the river. Contours of the water table indicate an average ground-water gradient of about 100 feet per mile along Nakai Creek to the San Juan River (Fig. 2). The altitudes of four small springs in the bottom of Nakai Creek coincide with that of the water table at the springs, indicating that in these places the bed of the creek intersects the water table. However, springs were not seen along the banks of the San Juan River. The gradient of Nakai Creek is about 85 feet per mile. Thus, the ground-water gradient is steeper than that of Nakai Creek, and both are controlled by the altitude of the San Juan River.

All the underflow in the Shinarump member and in the alluvium of Nakai Creek discharges to the San Juan River. The underflow through a 1/2-mile wide section across Nakai Creek, where the saturated thickness of the Shinarump is 50 feet and the ground-water gradient is 100 feet per mile, can be computed by the formula:

$$Q = PIA$$

where

Q = underflow, in gallons per day

P = coefficient of permeability, in gallons per day per square foot

I = hydraulic gradient, in feet per mile

A = area of flow cross section, in square feet

The coefficient of permeability of the Shinarump member is not known precisely, but estimates from hydrologic work done by the Ground Water Branch of the U. S. Geological Survey, Navajo Project, indicate that it may range from 20 to 100 gpd (gallons per day) per square foot. It could be higher, if the joint system is strongly developed in the area of Nakai Creek, or lower, if the joints are poorly developed or if the Shinarump member is silty.

$$Q = PIA$$

therefore, if

P = 20 gpd per square foot

then

$$Q = 20 \times \frac{100}{5,280} \times 50 \times 2,640$$

= 50,000 gpd (35 gpm) (56 acre-feet per year)

if

P = 100 gpd per square foot

then

Q = 250,000 gpd (175 gpm) (280 acre-feet per year)

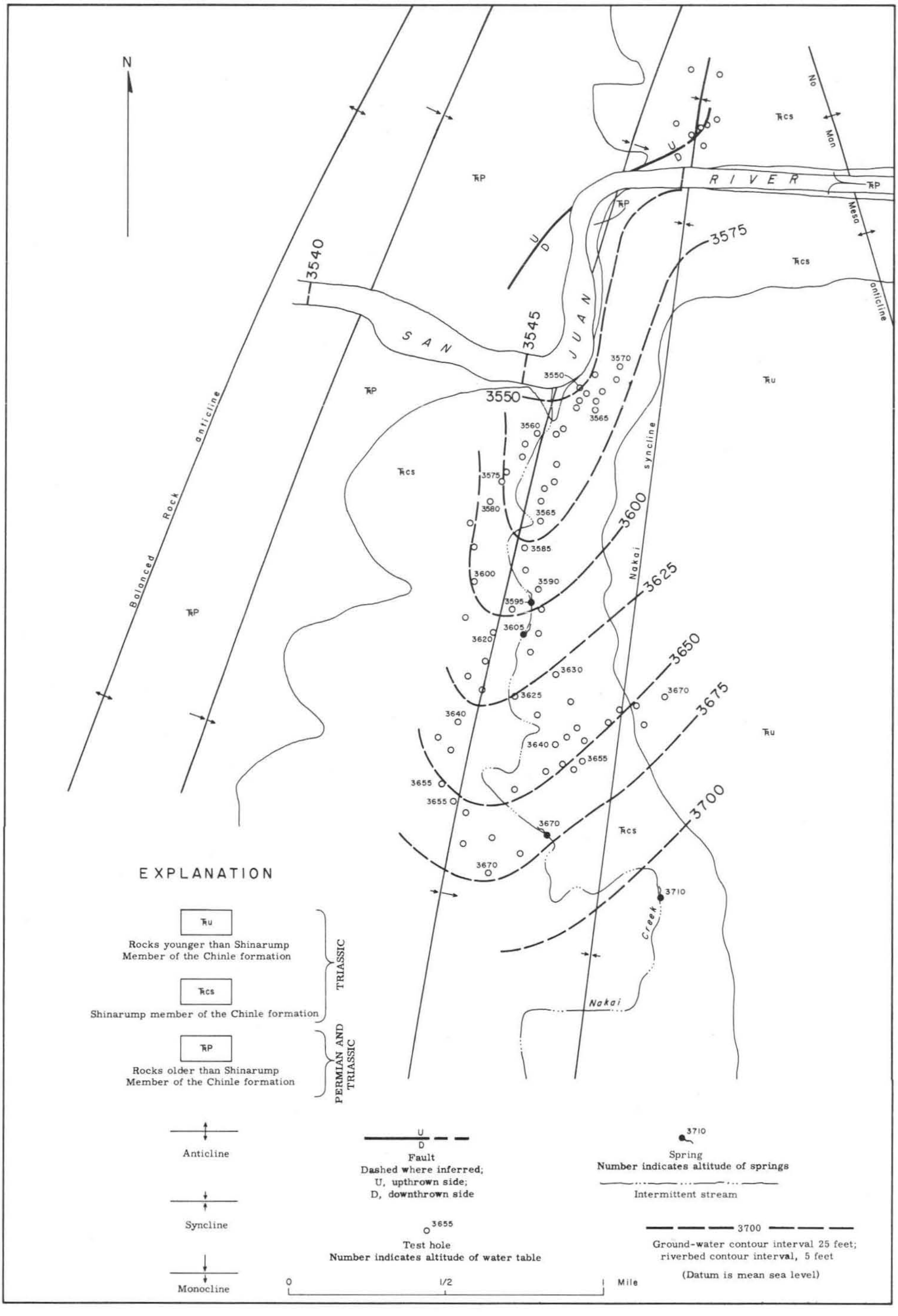

Figure 2.--Water-level contour map on the Shinarump member of the Chinle formation in the lower Nakai Creek area, Utah.

Thus, the discharge from the Shinarump across the section of Nakai Canyon adjacent to the San Juan River may range from 35 to 175 gpm. The small amount of discharge to the San Juan River is probably the main reason springs are not seen along the banks of the river.

The physiography of the narrow valley floor and steep gradients of Nakai Canyon and similar canyons in the Segi Mesas area are conducive to rapid runoff after a rain. The Shinarump member or other permeable rocks may be recharged temporarily by the stream runoff and hold some of the water as bank storage. Part of this water is returned to the surface drainage and part is lost to evaporation. All the underflow in the Shinarump discharges to the San Juan River and the gradient of the water table in the Shinarump may flatten out in the Nakai Creek area during drought. However, the water table never can be below the river bottom because the river penetrates the aquifer completely. During flood stage in the San Juan River, the aquifer would be recharged to some extent if the river level was higher than the water table. However, as the river level declined, the ground-water gradient in the Shinarump again would be toward the river.

In the Nakai Creek area the movement of ground water apparently is controlled predominantly by the altitude of the creek bottom. The ground-water levels may be influenced by the monocline to the west but, surprisingly, are not greatly related to the Nakai syncline (Fig. 2). Although the axis of the syncline is only half a mile east of the creek and the monocline, ground water moves across the axis of the syncline toward the creek channel, which is on the west flank of the syncline.

The difference in the rate of movement between ground water and surface water is an important factor in determining the availability and amount of water discharging from a basin within a certain time. The movement of surface water is faster than that of ground water. The surface runoff is related to climatic conditions during any given time interval. Ground-water velocities are extremely slow; the rate of movement depends on the permeability, porosity, and hydraulic gradient of the aquifer. The velocity of the ground-water movement through the Shinarump member in Nakai Creek may be calculated by using certain assumptions and the formula:

$$v = \frac{PI}{395p}$$

where

v = velocity of underflow, in feet per day

P = coefficient of permeability, in gallons per day per square foot; assumed to be 20-100 gpd per square foot

I = hydraulic gradient, in feet per mile

p = porosity of sediments, in percent (expressed as a whole number); assumed to be 30 percent

if

P = 20 gpd per square foot

then

$$v = \frac{20 \times 100}{395 \times 30} = 0.2 \text{ foot per day}$$

if

$$P = 100 \text{ gpd per square foot}$$

then

$$v = \frac{100 \times 100}{395 \times 30} = 1.0 \text{ foot per day}$$

Thus, the velocity of ground water would range from 0.2 to 1.0 foot per day, and a particle of ground water in the Shinarump member would take from 15 to 70 years to move a mile. If the hydrologic characteristics of the aquifer in Nakai Creek basin are similar to those in the area of the test holes, the time for water recharged to the Shinarump in the upper reaches of the basin to be discharged from the member at the San Juan River, a distance of about 30 miles, is between 450 and 2,100 years. In contrast, surface water flowing 12 fps (feet per second) moves a mile in about 7 minutes. If the drainage area of Nakai Creek is estimated roughly to be 150 square miles and the average precipitation 8 inches per year, the amount of precipitation on the area is about 64,000 acre-feet per year. If 3 percent (or 0.25 inch) of the precipitation becomes runoff (Langbein and others, 1959, pl. 1), runoff in Nakai Creek would be about 2,000 acre-feet per year. The highly impermeable Chinle formation crops out in much of the drainage basin, and the amount of runoff in Nakai Creek may be greater, probably less than 6,000 acre-feet per year. These amounts are very large, compared to about 300 acre-feet per year of ground-water discharge, but ground-water flow is more constant and is not subject to sudden variations in discharge as is streamflow.

There may be much surface-water runoff to the San Juan River in Nakai Creek that is not observed or recorded. Nakai Creek is ephemeral and is subject to flash floods, especially in the summer, because its drainage area lies in a canyon region where violent thunderstorms are common. Evidence of high runoff is found in a sharp, narrow gorge which encloses the creek 5 miles south of the San Juan River. At this point, a few logs carried in by flood water were left stranded on sandstone ledges about 40 feet above the stream bed. The gorge has an average width of at least 20 feet. If the velocity of the flood water was 12 fps at the level at which the logs were deposited, Nakai Creek would have been flowing about 10,000 cfs (cubic feet per second). If the high-water-discharge rate of 10,000 cfs continued for only an hour, the total discharge would have been about 800 acre-feet. The variation in the flow of Nakai Creek is great. Thus, in years of abnormal rainfall, runoff may be substantially greater or less than the yearly average.

The maximum flow of Nakai Creek during the last several centuries is estimated to have been not more than 25,000 cfs, because the Pueblo Indian ruins on the bank of the creek about 1-1/2 miles above its mouth have not been destroyed by stream erosion. These ruins, occupied probably in the twelfth century (Adams and Adams, 1959, p. 23), are only 15 feet above the creek bed. They lie beneath an overhanging ledge along the outside of an incised meander and were built from thin sandstone slabs weathered from the Shinarump member. The creek flows in a channel more than 150 feet wide. The presence of these ruins suggests that (1) no flood of sufficient intensity to destroy the ruins (more than about 25,000 cfs) has occurred in the last 800-900 years and (2) no appreciable change in the stream bed has taken place along this reach of Nakai

Creek since the occupation of the ruins.

CONCLUSIONS

In the Segi Mesas area, the broad Monument upwarp controls the regional movement of ground water to the Colorado and San Juan Rivers. Locally, anticlines, synclines, and the Navajo Mountain dome and the lithology of the sedimentary rocks affect ground-water movement and are important factors in developing water supplies. The success of a well may be dependent on its location in a syncline instead of an anticline. Relatively large yields of water from wells and springs may be the result of joints and fractures in the aquifer. The geology—permeable stratigraphic units, structure, and physiography—controls the recharge, movement, and discharge of water. All the water in the drainage basins of the Segi Mesas area of Arizona and Utah, ultimately, comes from precipitation. Some of the water discharges to the Colorado and San Juan Rivers as erratic runoff in the numerous creeks; some of the water moves slowly to the rivers as ground-water discharge from the aquifers.

Basic data are needed to understand fully the interrelations of hydrologic factors and geologic features. Stream-gaging stations would provide records of runoff now being estimated by indirect methods. Archaeological studies and the use of high-water marks provide clues to the amount of discharge of flood flows in the canyons. For example, the Pueblo Indian Ruins 800 to 900 years old in Nakai Canyon near the creek bed have not been destroyed by flood waters. Thus, maximum flood stages in the canyon can be approximated. If daily streamflow records were available, the hydrologic characteristics of the drainage basin would be defined more adequately. Infiltration and runoff studies would provide information as to the drainage capacity of the basin. Test drilling and aquifer tests are useful in defining the geohydrologic characteristics of the subsurface rocks. The amount and duration of rainfall related to temperature and to other climatological data are basic to an understanding of the hydrology. All these hydrologic factors when integrated with sufficient geologic data should provide a better knowledge of the water regimen in the Segi Mesas area of Arizona and Utah.

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