

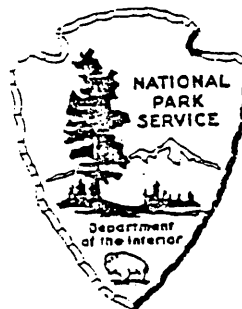
WATER RESOURCES

REPORT 80-1

GROUND WATER IN THE NAVAJO

NATIONAL MONUMENT AREA

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GROUND WATER IN THE NAVAJO NATIONAL MONUMENT AREA

by

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ABSTRACT

The Peabody Coal Company operates strip coal mines in the Navajo Indian Reservation. The operation withdraws considerable quantities of water from the N multiple-aquifer for industrial use. Navajo National Monument which is located 19 miles northwest of the Peabody Coal field also utilizes the same aquifer for water.

The rocks in the area are a sequence of Triassic, Jurassic, and Cretaceous rocks composed of mudstones, siltstones, and sandstones. Coal resources are located in the Cretaceous rocks, particularly in the Wepo formation which caps Black Mesa.

The N multiple-aquifer consists of the Triassic-Jurassic Navajo sandstone, the Triassic Kayenta formation, and the Triassic Lukachukai member of the Wingate sandstone. The principal lithology of these units is sandstone. The Navajo sandstone is the chief aquifer in this system. The Carmel formation overlies the Navajo and confines the N multiple-aquifer. The Triassic Chinle formation underlies the Wingate sandstone and acts as the lower confining unit to the aquifer.

Structurally, the Organ Rock Monocline plunges the N multiple-aquifer beneath Black Mesa. At the Peabody well field depths to the Navajo sandstone approach 2500 feet. Artesian conditions exist. The Navajo sandstone at Betatakin no. 2 well is exposed at the surface and unconfined conditions occur. Betatakin no. 2 well is located near the very steep-walled Tsegi Canyon, which exposes the contact between the Navajo and Kayenta and largely drains the Navajo, thus limiting the saturated thickness of the Navajo in such areas.

In the Black Mesa area, the transmissivity values of the Navajo range from 75 to 350 square feet per day; the hydraulic conductivity from 0.40 to 0.70 feet per day. The artesian part of the aquifer has storage coefficients from 10^{-3} to 10^{-4} , and the unconfined part of the aquifer from 0.10 to 0.15. The recharge area for the artesian portion of the aquifer has an area of about 100 square miles, compared to the surface area of 3,000 square miles of the aquifer beneath Black Mesa. Rate of groundwater movement is about 2 to 4 feet per year.

Betatakin no. 2 well has a total depth of 753 feet. The static water level sits at 535 feet BSL. An aquifer test showed the water table dropped 57 feet after 19.3 hours of pumping at a discharge of 14.2 gpm. The coefficient of transmissibility is 127 gpd/ft. Specific capacity is 0.27 gpm/ft. No stabilization occurred. A recovery of 90 per cent occurred 80 minutes after pumping ceased.

Domestic wells near Betatakin no. 2 well also utilize water from the Navajo sandstone. These wells probably will not affect water levels at Betatakin no.2 well at current discharge rates. An annual withdrawal of 4,200 acre feet of water by the Peabody Coal Company probably far exceeds the recharge rate. The mining of the groundwater could have an effect upon the Betatakin no. 2 well. U.S.G.S. monitored wells around the northern periphery of Black Mesa have shown no noticeable effects on the groundwater table there to date. Currently, the U.S.G.S. is constructing a model to determine the long-term effects of continued withdrawals at the Peabody water well field. It is planned for release spring 1980.

INTRODUCTION

The Peabody Coal Company operates strip coal mines on Black Mesa situated in the Navajo Indian Reservation. The operation withdraws a considerable volume of groundwater (approximately 4200 acre-feet per year) from beneath Black Mesa to transport coal slurry and furnish water for other industrial necessities. The strip mining operation began in 1970 and is scheduled to be completed by 2015.

Navajo National Monument is located about 19 miles northeast of the Peabody Coal Company's water well field (see figure 1 for locations). Groundwater utilized by both the Peabody Coal Company and the National Park Service is derived from a common aquifer, the N multiple-aquifer. Several wells in the area near Navajo National Monument also supply groundwater for domestic, stock, and public use from the N multiple-aquifer system.

This preliminary report is intended to investigate the possible adverse effect of the pumpage of such large volumes of groundwater at the Peabody well field and of local water wells upon the groundwater supply at Navajo National Monument. Included in the report will also be hydrogeologic data about the Betatakin no. 2 well which supplies water at Betatakin Ruins, Navajo National Monument. The scope of this report will concern itself with pertinent geological and hydrological settings and relationships.

STRATIGRAPHY AND GROUND WATER

Rocks in the northern Black Mesa area are a sequence of Triassic, Jurassic, and Cretaceous age rocks, predominantly composed of mudstones, siltstones, and sandstones. Coal resources on or near the surface of northern Black Mesa are predominantly located in the Wepo Formation which caps much of the mesa.

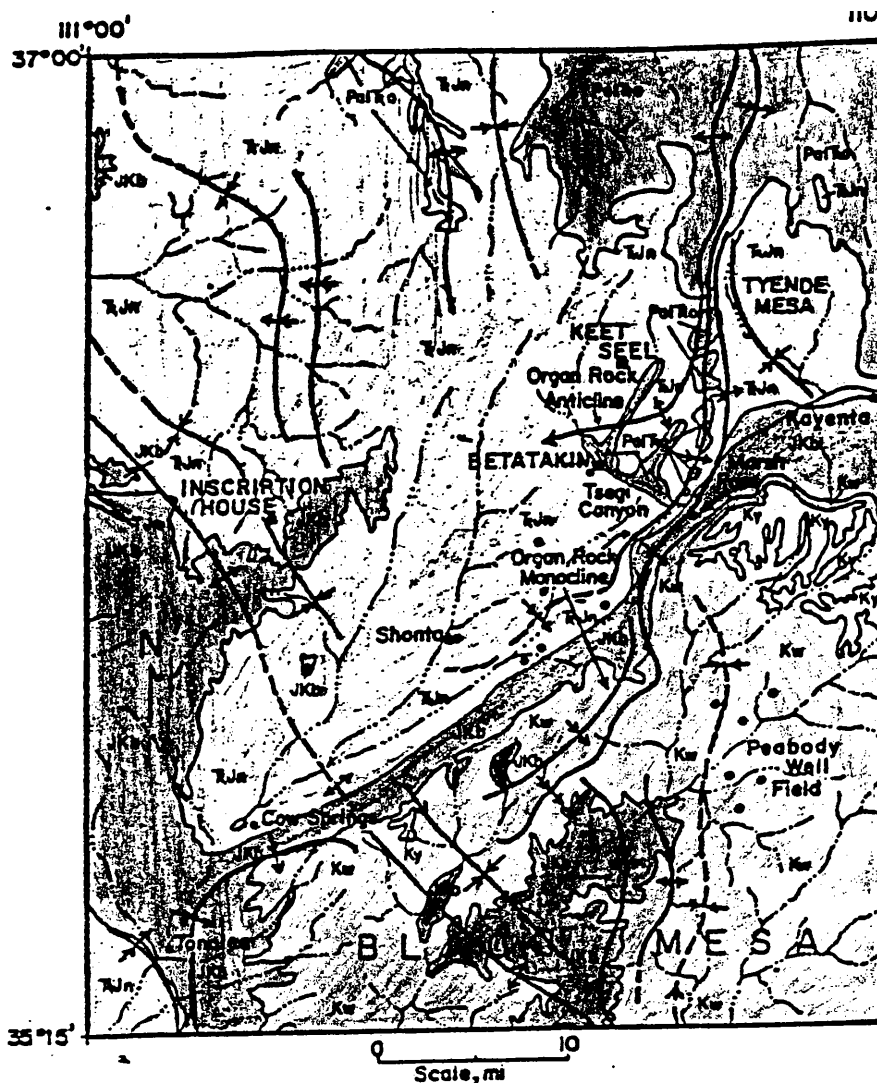
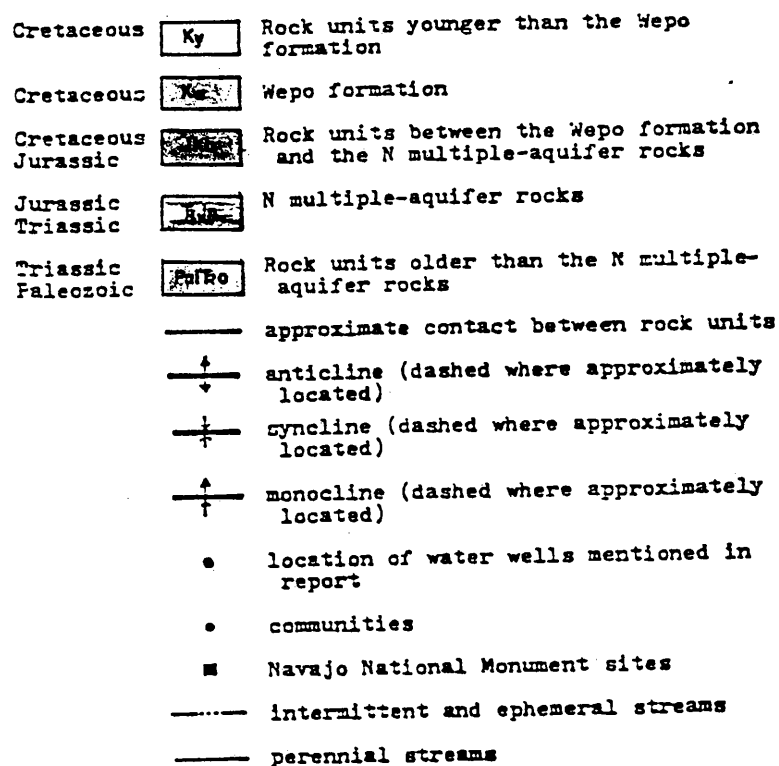


FIGURE 1. Geologic map of the Navajo National Monument area, northeastern Arizona



The upper Cretaceous Wepo formation of the Mesa Verde group consists of alternating beds of olive-gray siltstone, coal, and yellowish-gray sandstone. The coal deposits in the Wepo formation are restricted to the northern section of Black Mesa. The better coal deposits of the formation occur in its upper half. Coal in the area also occurs in the Toreva formation and the Dakota sandstone which are stratigraphically beneath the Wepo formation and above the N multiple-aquifer rocks.

In the northern Black Mesa and Navajo National Monument area, ground water is drawn from the N multiple-aquifer system. This continuous system consists (in descending stratigraphic order) of the Navajo sandstone, the Kayenta formation, and the Lukachukai member of the Wingate sandstone, which are Triassic and Jurassic formations of the Glen Canyon group. The Navajo sandstone is the chief aquifer in this continuous system.

The Jurassic Carmel formation which overlies the Navajo sandstone is predominantly a red siltstone in the area. Thus, it acts as a confining bed and creates the artesian conditions of the Navajo sandstone beneath Black Mesa and also prevents any significant recharge to the N multiple-aquifer from the surface and from stratigraphically higher units at Black Mesa.

The Triassic Chinle formation underlies the Wingate sandstone in the area. The mudstones and siltstones of the Chinle formation act as a lower confining bed, preventing water transfer between the N multiple-aquifer system and units beneath this formation.

The Navajo sandstone is Triassic and Jurassic in age. In the study area, this sandstone is quite uniform lithologically. The sandstone is composed

of very fine to medium textured, subrounded sand grains, and is weakly cemented with calcium carbonate. The prominent large scale high-angle eolian crossbeds of this unit are most conspicuous. The Navajo sandstone near Tonalea is about 950 feet thick. Towards the southeast the unit thins until it pinches out along a line that extends from near Keam's Canyon to about 10 miles southeast of Rough Rock (see figure 2).

In the Navajo National Monument and northern Black Mesa areas, the Kayenta formation is predominately a pale-red crossbedded sandstone. However, the formation grades to a grayish-red mudstone, siltstone and silty sandstone towards the southwest portion of Black Mesa. The Kayenta formation then acts as a lower confining unit to the Navajo Sandstone. The Lukachukai member of the Wingate sandstone underlies the Kayenta formation in the area. This member is a reddish-brown fine-grained crossbedded sandstone of eolian origin. Figure 1 illustrates the surface extent of the N multiple-aquifer and the Wepo formation in the area.

STRUCTURE AND GROUND WATER

Black Mesa is a dominant topographic high on the Navajo-Hopi Indian Reservation that stands out about 500 to 1000 feet above the surrounding area. The mesa is situated on the structural center of the Black Mesa basin. Triassic and Jurassic rocks dip gently towards the mesa except along the west and northwest sides, where several monoclines plunge beneath the mesa. Navajo National Monument is located from 6-16 miles north to northwest of the northwest side of Black Mesa. The Peabody well field is located about 13 miles southeast of this northwest side.

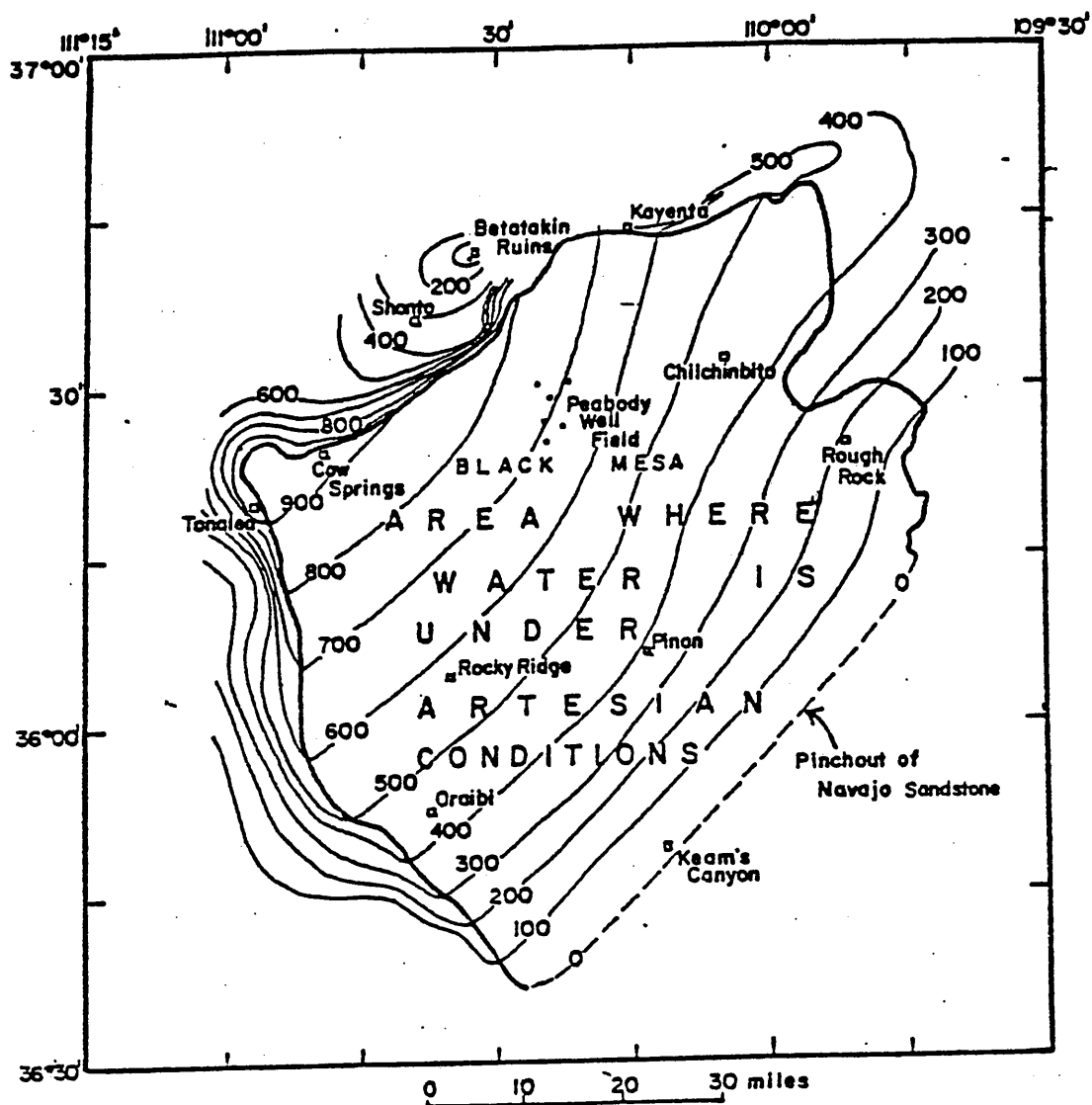


FIGURE 2. Approximate saturated thickness of the Navajo sandstone. Adapted from McGavock and Levings, 1973.

EXPLANATION

— Line showing approximate saturated thickness of the Navajo sandstone. Interval 100 feet.

• Well

Structurally, the Organ Rock monocline lies approximately along this northwest edge of Black Mesa between the monument and the Peabody well field. The monocline dips between 5° to 42° to the southeast and east. Dips have the highest values in the Marsh Pass area. Monoclines exert a strong influence on the movement and occurrence of water in sedimentary rocks. Thus the N multiple-aquifer is unconfined where exposed at the surface and is confined in the area where the Organ Rock monocline has downthrown the aquifer. Figure 1 demonstrates the pertinent structures in the area.

All three areas of Navajo National Monument, Betatakin, Inscription House and Keet Seel Ruins, are situated in the vicinity of cliffs formed by the erosion of rocks of the N multiple-aquifer. Where the contact between the Navajo sandstone and the Kayenta formation is exposed at the surface, usually in very steep-walled canyons, natural discharge occurs in the form of springs and seeps. Very near these canyons the Navajo sandstone is largely drained and saturated thickness is less than 10 feet (Dennis, 1962). The Navajo sandstone may be dry in such zones. Navajo National Monument's Betatakin no. 2 well in 1962 has a saturated thickness of 75 feet in the Navajo Sandstone.

The N multiple-aquifer in the area northwest and north of Black Mesa exists in an unconfined condition. Saturated thickness increases to the west and southwest of Tsegi Canyon (see figure 2). Formations exposed in Tsegi Canyon and branching canyons are the Navajo sandstone, the Kayenta formation, the Lukachukai member of the Wingate sandstone and the Chinle formation.

At Betatakin Ruins, the Navajo sandstone dips away from Tsegi Canyon to the west, southwest, and south at about 2° . Proximity to the canyon walls and the presence of the Organ Rock anticline coupled with the dip of the

stratigraphic units west of Tsegi Canyon limit the possibility of higher recharge rates to Betatakin no. 2 well at Betatakin Ruins where the monument headquarters are located.

GROUND WATER HYDROLOGY

From twelve wells around Black Mesa, the values of the transmissivity of the Navajo Sandstone range from 75 to 350 square feet per day (McGavock and Levings, 1973). The transmissivity is governed primarily by the saturated thickness of the aquifer. Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. In the Black Mesa area, the saturated thickness and transmissivity of the Navajo sandstone reach a maximum near Tonalea. See Figure 2 for approximate saturated thickness of the Navajo sandstone. For these same twelve wells, the hydraulic conductivity ranges from 0.40 feet per day on the northwest side of Black Mesa to 0.70 feet per day on the south side (McGavock and Levings, 1973). Hydraulic conductivity is the transmissivity divided by the saturated thickness and is the volume of water that will move in unit time under a unit hydraulic gradient through a unit area of the aquifer at right angles to the direction of flow. The hydraulic conductivity of the Navajo sandstone tends to increase from the northeast to the southwest.

The storage coefficient for the Navajo sandstone is not determined. In the artesian portion of the aquifer, data from aquifer tests and performance of wells show that the storage coefficient probably ranges from 10^{-3} to 10^{-4} (McGavock and Levings, 1973). In the unconfined portion of the aquifer, the specific yield is equal to the storage coefficient and is estimated to range from 0.10 to 0.15 (McGavock and Levings, 1973). The storage coefficient is

dimensionless and is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. The confined and unconfined portions of the aquifer have storage coefficients which differ by a factor of 2 or 3. The relatively small storage coefficients of the Navajo sandstone beneath Black Mesa is due to the heavy overburden of sediment, which closes much pore space.

Based on geologic and hydrologic maps of the area published by the USGS, the outcrop area of the Navajo sandstone which recharges the Navajo sandstone beneath Black Mesa has an area of approximately 100 square miles. The area of the Navajo sandstone underlying Black Mesa is about 3,000 square miles. This recharge area lies northwest and north of Black Mesa, and is situated in the Cow Springs, Shonto, Betatakin Ruin, and Tyende Mesa area. See figure 3 for location. Navajo National Monument is situated in the recharge area.

The rate of ground water movement in the recharge area is calculated to be from 2-4 feet per year (McGavock and Levings, 1973). These rates are supported by an age of 15,500 years for water withdrawn about 40,000 feet down gradient from the recharge area (McGavock and Levings, 1973). Groundwater from the recharge area moves southeasterly, southwesterly, and southerly to beneath Black Mesa. There the water divides and flows in northeasterly and southwesterly directions out of the Black Mesa basin. Figure 3 shows the approximate potentiometric contours of the N multiple-aquifer and directions of ground water flow in the aquifer.

In the Peabody well field, the Navajo sandstone is overlain by about 2,500 feet of Jurassic and Cretaceous sediments. Beneath Black Mesa, the N multiple-aquifer is artesian, and at the Peabody well field up to 2,000 feet of head occurs. The

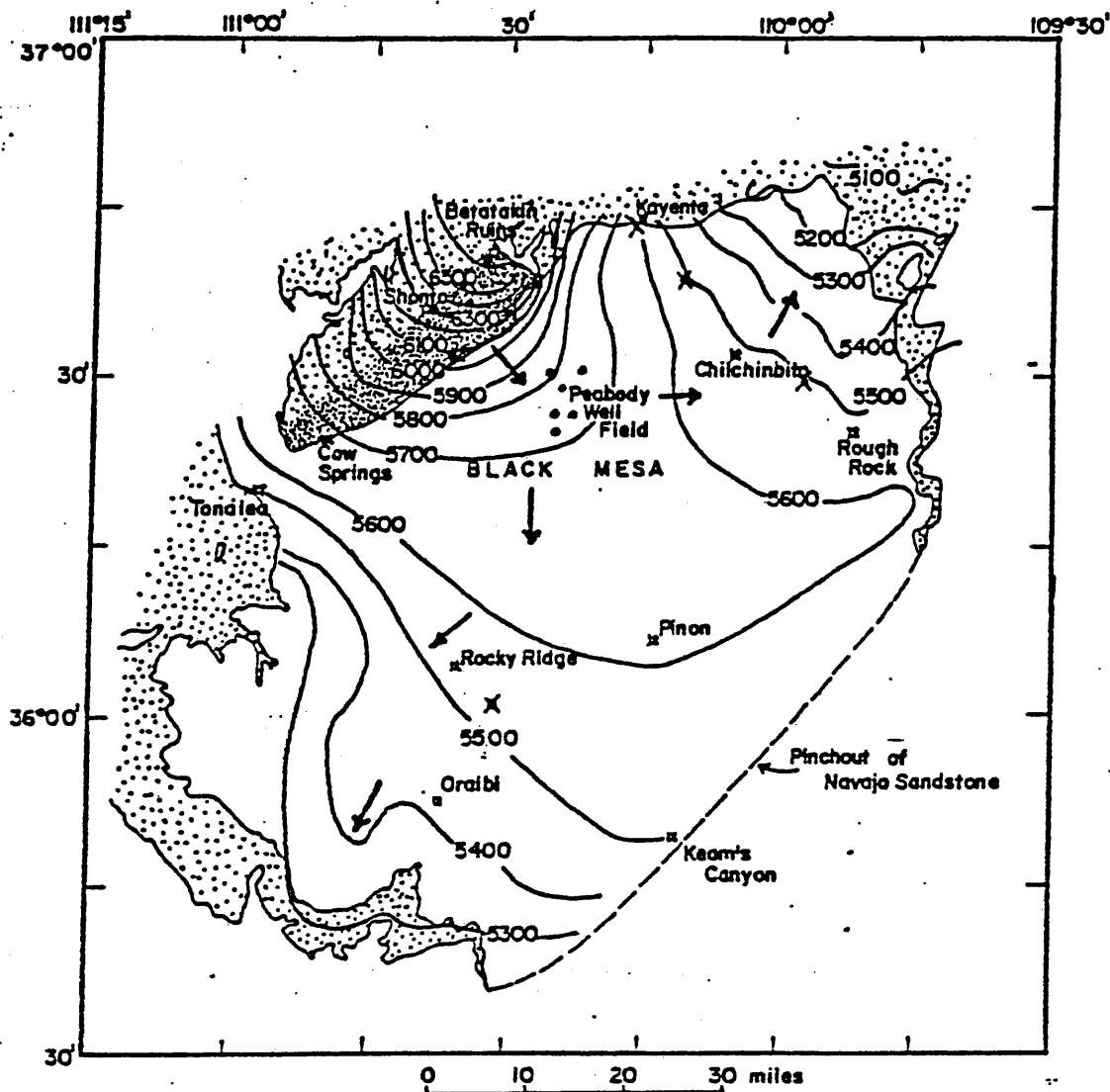


FIGURE 3. Approximate altitude of the potentiometric surface of the water contained in the Navajo sandstone. Adapted from McGavock and Levings, 1973.

EXPLANATION

-  Area of outcrop of the Navajo Sandstone
-  Area or recharge to the artesian part of the Navajo sandstone
- Approximate potentiometric surface contour, as of 1970. Shows static head in the Navajo sandstone. Contour interval 100 feet. Datum is mean sea level.
- ← General direction of groundwater movement in the Navajo sandstone
- Well
- × Observation well

wells each have a total depth of between 3,500 to 3,750 feet. The approximate altitude of the potentiometric surface of the water contained in the N multiple-aquifer here is between 5,700 to 5,800 feet. The discharge of each well ranges from 525 to 550 gpm.

Betatakin no. 2 well was originally drilled to a depth of 780 feet. The hole was later backfilled to a total depth of 753 feet. The altitude of the surface at the well site is 7,230 feet. The water table was first encountered at 555 feet below the surface. Afterwards the water table rose to 523 feet below the surface (altitude 6,695 feet).

At the Betatakin no. 2 well, the Navajo sandstone was encountered from the surface to 550 feet beneath the surface. The well was terminated 120 feet into the Kayenta formation. In this area the Kayenta formation is approximately 150 feet thick. The well site lies on an eroded surface of the Navajo sandstone.

A pump test performed on Betatakin no. 2 well by the National Park Service in November 1973 showed the water table dropped 57 feet after 19.3 hours of pumping. No stabilization occurred. The average pumping rate was 14.2 gpm. The computed coefficient of transmissibility is 127 gallons/day/foot (17 square feet per day). The discharge-drawdown ratio is an estimate of the specific capacity of a well. Specific capacity of the Betatakin no. 2 well from the above pump test is 0.27 gpm/ft.

The USGS Water Resource Division in July 1962 also tested the Betatakin no. 2 well. After a total pumping time of 48 hours, the water table dropped 91.4 feet. Average discharge was determined to be 20 gpm. Specific capacity was 0.22. Stabilization of the water table appeared to occur at approximately

626.1 feet below the surface (91.4 feet below SWL) after 32 hours of pumping. However, the discharge rate was not held constant during the initial 6.9 hours. Discharge rates varied from 15-50 gpm. Afterwards, the discharge rate was constant at 20 gpm. At this discharge rate, stabilization apparently occurred at the above mentioned level.

Recovery data from the 1973 pump test showed that in 80 minutes the water level had risen 49.5 feet (7.5 feet below SWL). One hundred eighty minutes after pumping ceased in the 1962 pump test, the water level had recovered 82.0 feet (9.4 feet below the SWL of that test). In the first case, 87% recovery occurred and in the second, 90%. Such recovery indicates good transmissivity.

The static water level at Betatakin no. 2 well as measured July 1962 was 534.7 feet below the surface. Depth to the static water level in November 1973 was 541.7 feet below the surface. This lowering of the static water level of 7 feet is probably the aquifer's natural response to annual and seasonal variation in precipitation. Approximately 50-65% of the annual precipitation at Betatakin Ruins falls in July and August.

Wells which lie in the recharge area near Betatakin Ruins (see figure 1 for location) are southeasterly and southwesterly directions from Betatakin no. 2 well are used for domestic and stock purposes. The well at Shonto is also a public water source. These wells maintain small withdrawals from the N multiple-aquifer and their static water tables are located downgradient from that at Betatakin no. 2 well. Discharge varies from 4 to 44 gpm.

The above wells enjoy a greater saturated thickness in the Navajo. Depths to the water table vary from 8.2 feet at Shonto (which is probably due to water table in the alluvium which overlies the Navajo) to 450 feet at a well

located 7 miles south-southeast of Betatakin no. 2 well. The average depth to the water table is 292 feet (excluding the Shonto well). Saturated thicknesses in the Navajo Sandstone of these wells may be up to 290 feet. All but one of these wells were drilled in the fifties and early sixties.

In 1972, 3,700 acre-feet of water was withdrawn from the Peabody well field. The current estimated withdrawal, according to H. T. Smith (Personal communication, 1979), Peabody Coal Company hydrologist, is 4,200 acre-feet per year.

An artesian aquifer is a pressure system. Any withdrawal which greatly surpasses the recharge rate will reduce the artesian pressure over a large area. As water is continually pumped out of the N multiple-aquifer, the piezometric surface will lower until it reaches the northern edges of the mesa. At this point, the recharge area will begin to be flushed out at much more rapid movement rates.

Considering the annual precipitation of about 12 inches per year at Betatakin Ruins, high evapotranspiration rates (arid to semiarid climate), and the very small fractional infiltration percentages of the total annual precipitation, recharge rates will not support such a large withdrawal.

In the Peabody well field, seven wells have been drilled by the Peabody Coal Company. Figure 1 shows the location of these wells. Peabody no. 1 well was drilled as an exploratory well and is not used currently. Peabody no. 2 through no. 7 wells are currently in use. Two new wells are in planning to provide more water for dust control compliance at the Peabody Coal Company operations on Black Mesa.

In April 1972, four wells (figure 3) along the northern periphery of the mesa were equipped with continuous water level recorders to check the possible effects of the industrial pumpage on community wells. One of these wells lies along the northwest side of Black Mesa where recharge to the aquifer occurs. The U.S.G.S. Water Resource Division at Flagstaff, Arizona, has reported no change in the water levels of these observation wells as of this year (1979). An exception is the lowering of the static water level at Kayenta due to large demands on a limited aquifer by the small town. Also during the last 20 years, water levels have been measured periodically in several windmill wells along the periphery of the mesa. No permanent declines have been detected yet.

CONCLUSIONS AND SUGGESTIONS

At present, no evidence is available to conclude that the withdrawals at Peabody well field and those of neighboring local wells might effect the Betatakin no. 2 well in the immediate future, although it may be said that an effect will occur sometime in the future. The effects of the extensive withdrawals at the Peabody well field will probably not be felt for decades or even centuries as attested by groundwater movement rates of 2-4 feet per year in the unconfined aquifer. These rates are lower in the confined portion of the aquifer beneath Black Mesa. A definite time estimate for the interference to begin is not available. Recharge amounts and rates to the N multiple-aquifer beneath the mesa are not known, but the rate of groundwater movement is too slow for recharge to balance the withdrawal in the artesian part of the aquifer.

Since the U.S.G.S. is monitoring for possible effects of the mining operation on neighboring groundwater supplies, I would suggest that the National Park

Service keep in close contact with the U.S.G.S. and request a copy of their report on the monitoring operation each year. The U.S.G.S. is presently constructing a computer model to predict when this effect might occur and to what extent the effect will cover. It is planned to be released in the spring of 1980.

Local wells near the ruins probably will have a negligible effect on the Betatakin no. 2 well, unless demand increases significantly. It is suggested to measure the depth to the water table at Betatakin no. 2 well several times a year to determine if local usage may somehow influence the water supply. The appropriate time period to measure this depth ought to be during low visitation when water demand is low and supplies in storage tanks are sufficient for several days. To allow full recovery of the static water level, water should not be withdrawn for 48 hours. Then the datum may be taken.

In the event that the Betatakin no. 2 well cannot supply future water needs, a new well ought to be drilled further to the west or southwest of the present site to benefit from a greater saturated thickness of the Navajo sandstone. From the presented data, the well supplies a sufficient amount of water at present.

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