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Moqui

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Mr. William Fitzgerald
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Grand Canyon, Arizona 86023

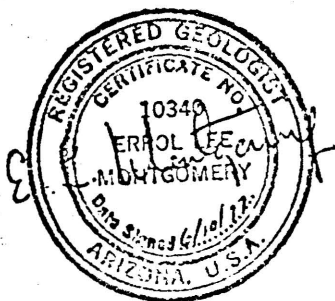
Dear Mr. Fitzgerald:

I have concluded field studies and office investigations for the Moqui wells as outlined in my proposal to you dated January 26, 1977. The analysis is contained in the accompanying letter report and indicates that the wells should probably be abandoned. If you decide to attempt to place wells (A-30-2)25b and (A-30-2)25c into production at small yields, the costs for pulling the existing pumping equipment, bailing the hole, and resetting the pumping equipment will be a minimum of approximately \$1,400 for one well. These costs are based on the assumption that the pumps can be pulled, and that the pumping equipment in the well need not be replaced.

Review of records for other wells and inspection of geologic features in the Moqui-Tusayan area suggests that the Toroweap and the Coconino aquifers do not contain sufficient water to provide a sustained supply to wells. The Redwall-Temple Butte- Muav aquifer is saturated in the Moqui area, and although drilling depths and costs will be large, these formations may yield more than 100 gallons per minute of water to properly located and constructed wells.

Respectfully submitted,

Errol L. Montgomery



GROUNDWATER CONDITIONS AND POTENTIAL
YIELD OF WELLS, MOQUI-TUSAYAN AREA,
COCONINO COUNTY, ARIZONA

CONCLUSIONS AND RECOMMENDATIONS

The following salient conclusions and recommendations are based on a field investigation and analysis of available data from exploration and water wells in the Moqui-Tusayan area.

CONCLUSIONS

- A. Groundwater in the Toroweap Formation and in the Coconino Sandstone occurs as small and thin perched groundwater bodies. In the Moqui-Tusayan area, these perched reservoirs commonly become depleted after several years or less of pumping. Geologic structures and fracturing which may cause the accumulation of groundwater at the base of the Coconino appear to be sufficiently abundant to have ruptured the underlying aquitards; hence, little water is stored in the base of the Coconino.
- B. Fracturing and solutioning activity along these fractures provides conditions favorable for development of large amounts of groundwater, via properly located and constructed wells, from the Redwall Limestone, the Temple Butte Limestone, and the Muav Limestone. The depth to the top of this limestone

aquifer sequence is approximately 2,450 feet, and the thickness of this limestone sequence is approximately 915 feet.

- C. Two of the five Moqui wells are the McAfee-Meeks No. 1 and No. 2 wells. These wells are listed in Table 1, and their approximate locations are shown on Figure 2. The first of these wells was drilled to the base of the Coconino which was dry and the well was plugged back and completed in the Toroweap aquifer. The second well was drilled to the base of the Toroweap and was completed at that depth. After several years of pumpage, declining water levels and problems with caving resulted in non-use of the wells. The wells have subsequently experienced further caving and the pumping equipment is probably locked into position by the caved material.

RECOMMENDATIONS

- A. The five Moqui wells should be abandoned due to problems stemming from depletion of the limited perched aquifers in the Toroweap and from caving in the wells which has probably locked the pumping equipment in place.
- B. A test hole could be constructed in the Moqui-Tusayan area to determine the productivity of the Redwall-Temple Butte-Muav aquifer.

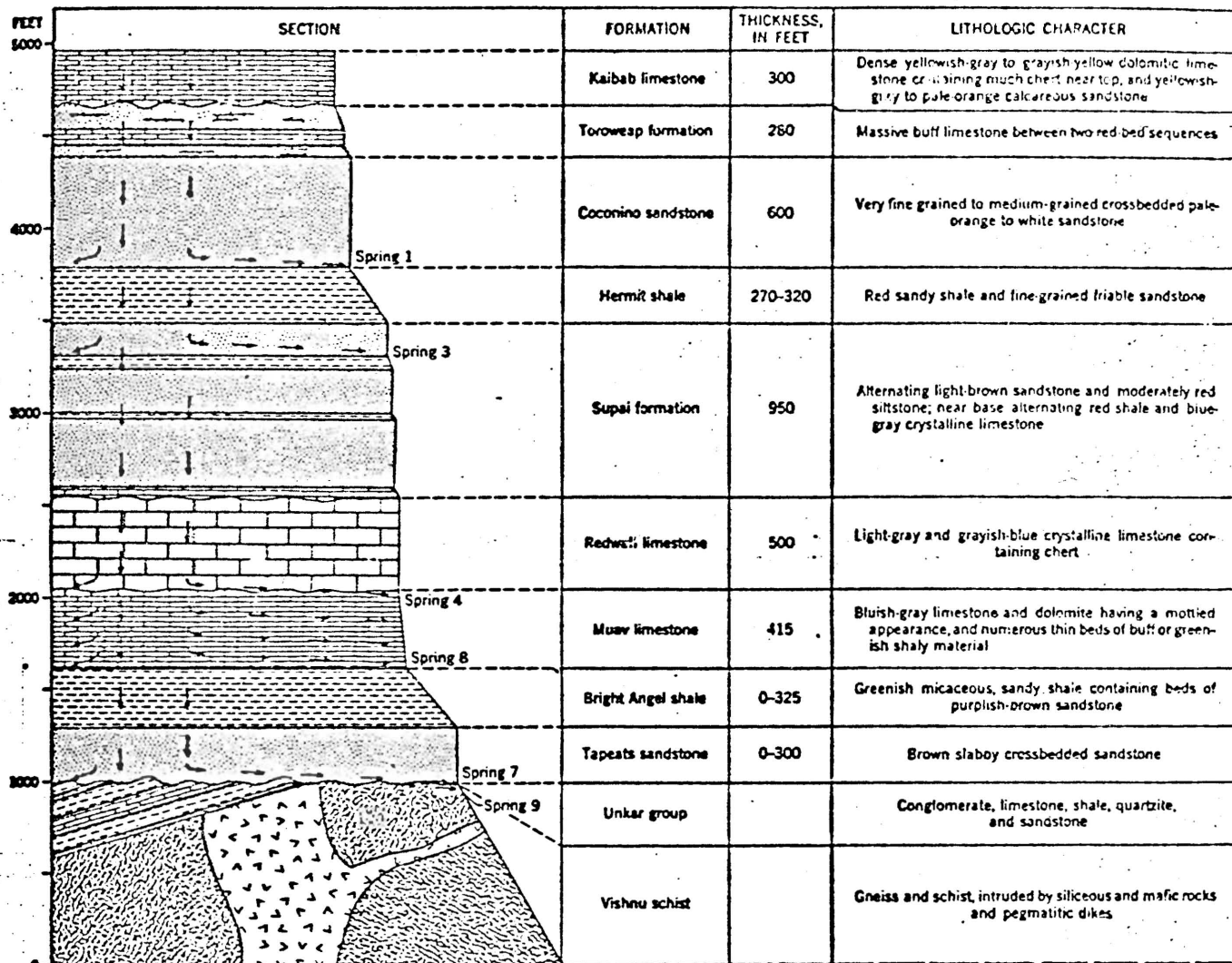
GENERAL HYDROGEOLOGICAL CONDITIONS

It is essential to have an adequate knowledge of the geologic framework to evaluate the groundwater resources of an area. In the Moqui-Tusayan area, the occurrence of groundwater is related not only to the lithologic character of the formations but also to the geological structural features.

All existing wells in the Moqui-Tusayan area yield water from Paleozoic strata which are the lateral equivalents to the geologic formations exposed in the upper part of the Grand Canyon. Rocks of Precambrian age lie below the Paleozoics but are not considered important as they occur at depths beyond economical drilling methods and are not known to yield substantial quantities of water to springs or wells.

PALEOZOIC ROCKS

The Paleozoic formations in the Grand Canyon in descending order are: the Kaibab Limestone, the Toroweap Formation, the Coconino Sandstone, the Hermit Shale, the Supai Formation, the Redwall Limestone, the Temple Butte Limestone, the Muav Limestone, the Bright Angel Shale, and the Tapeats Sandstone. These formations are believed to lie at economical drilling depths, although the Redwall, Temple Butte, and Muav Limestones have not been developed as a source of groundwater in much of northern Arizona. The thickness of the Paleozoic formations and the generalized patterns of groundwater circulation are shown on Figure 1.



The downward percolation of ground water is shown diagrammatically

**COLUMNAR GEOLOGIC SECTION NEAR GRAND CANYON VILLAGE, ARIZONA,
SHOWING THE STRATIGRAPHIC POSITION OF SELECTED SPRINGS**

377866 O - 61 (in pocket)

FIGURE 1 (PLATE 14)

(From Metzger, D. G., 1961, U.S. Geological Survey Water-Supply Paper 1475C)

KAIBAB LIMESTONE: The Kaibab Limestone is a thick- to thin-bedded, jointed, and sandy dolomitic limestone. It crops out over large areas in northern Arizona, forms the rim-rocks of the Grand Canyon, and is the surface rock in much of the Moqui-Tusayan area. The Kaibab is a brittle formation and is extensively fractured in areas where geological structural movements have occurred. Water percolation through these fractures has enlarged the openings and has created extensive cavernous areas. Where the Kaibab Limestone is exposed, surface water percolates readily downward via the fractures and solution caverns, and thus the Kaibab comprises an important recharge medium. Because the Kaibab does not store water, it is not an aquifer.

TOROWEAP FORMATION: The Toroweap Formation consists of sandstone, shale, and limestone. The Toroweap is considered to be a minor aquifer in the study area and yields small amounts of water to eight wells (Table 1). The lithology of the sandstone beds provides storage and permits transmission of groundwater. Shale beds within the formation form aquitards and locally cause small accumulation of perched groundwater. Because the permeable sandstone beds and the shale aquitards are of limited thickness, the potential storage and sustained yield of groundwater from the Toroweap is small, and many wells have failed after variable periods of production.

COCONINO SANDSTONE: The Coconino Sandstone is a light-colored, very fine- to fine-grained, friable, cross-bedded sandstone. The degree of cementation varies but the formation is brittle and

contains extensive fractures near fault zones. The Coconino is a principal aquifer in much of northern Arizona, but in the Moqui-Tusayan area only two wells were designed to produce water from this formation, and records suggest that both wells are dry. The lithologic character of the Coconino indicates a low to moderate permeability and porosity, and in many areas the formations may contain substantial quantities of water. However, the Coconino is an aquifer only where the underlying Hermit Shale and Supai Formation form an aquitard and where favorable structures are present.

HERMIT SHALE AND SUPAI FORMATION: The Hermit Shale and Supai Formation consist mostly of red siltstone and fine-grained sandstone. Both formations are important aquitards. Because these formations are nearly impermeable, groundwater is often perched in the base of the Coconino Sandstone on top of the shaly strata of the Hermit and Supai in areas where the groundwater does not drain laterally and does not percolate downward via extensively fractured strata. One well in the Moqui-Tusayan area is reported to produce a small amount of water from sandstone strata in the Hermit Shale. Interviews of local residents indicate that this well is presently dry.

REDWALL LIMESTONE, TEMPLE BUTTE LIMESTONE, AND MUAV LIMESTONE: The Redwall, Temple Butte, and Muav Limestones lie below or partly below the regional water table and comprise an extensive potential aquifer in the south Grand Canyon area. The presence of solution channels which have developed along fracture zones provides for the transmission and storage of large amounts of groundwater. Large

springs (see Table 2) whose aggregate discharge rate exceeds 160 cubic feet of water per second discharge from these formations where they crop out in the southern wall of the Grand Canyon. The depth to the top and to the base of this limestone sequence in the Moqui-Tusayan area is approximately 2,450 and 3,365 feet respectively.

BRIGHT ANGEL SHALE AND TAPEATS SANDSTONE: The Bright Angel Shale is composed chiefly of mudstone and shaly strata but also contains minor sandstone and limestone strata. The Bright Angel functions as an effective aquitard; no large springs issue from formations below this shale. The Tapeats Sandstone consists of cross-bedded, poorly sorted, coarse sandstone and conglomerate. Because the Tapeats is overlain by the Bright Angel Shale aquitard, only small amounts of water issue from springs in the Tapeats.

STRUCTURAL FEATURES

The major geologic structures in the Moqui-Tusayan area are the northeast trending Vishnu and McKee Faults and the Tusayan structurally depressed area. The regional dip of the Paleozoic strata ranges from $\frac{1}{2}^{\circ}$ to $1\frac{1}{2}^{\circ}$ and is to the southwest.

The Vishnu Fault and the McKee Fault cut rocks in the Grand Canyon where caverns occur in the limestone rocks along these fault traces. The Vishnu Fault crosses State Highway 64 approximately $\frac{1}{2}$ mile south of Moqui. The McKee Fault crosses Highway 64 at Tusayan where this fault and other minor faults bound a large structurally downthrown or depressed block.

The effects of faulting on movement and occurrence of groundwater in the Moqui-Tusayan area cannot be over emphasized. Recharge from stream-flow percolates readily downward through the fractured rocks to the underlying aquifer systems. Solution cavities, which also enhance water movement, are concentrated along these fractures.

GROUNDWATER FEATURES

EXISTING WELLS

At present (June, 1977) records are available for eleven wells in the Moqui-Tusayan area, sufficiently nearby to provide data pertinent for this study. These records are summarized in Table 1. These wells yield groundwater from perched aquifer bodies in the Toroweap Formation or near the base of the Coconino Sandstone. Several wells, which produced small amounts of water when drilled, are presently dry.

The depths of the wells range from 514 to 1,275 feet. Several wells which encountered perched groundwater bodies in the Toroweap were originally drilled to the base of the Coconino. However, when the Coconino was found to be dry, these wells were plugged back to the base of the Toroweap where they were completed.

Static water levels in wells which penetrated a groundwater reservoir range from 430 to 1,020 feet below land surface. Precise data are not available; however, records indicate that the saturated thickness in the Toroweap aquifer originally ranged from 14

TABLE 1. WATER WELL DATA, MOQUI-TUSAYAN AREA, COCONINO COUNTY, ARIZONA

Remarks: C - quality of water data available
L - drillers' log available

Location	Date Completed	Reported Depth of Well	Diameter of Casing (inches)	Land Surface Altitude*	Water Bearing Strata	Static Water Level		Pump Rate (gpm)	Remarks
						Feet Below Land Surface	Date Measured		
(A-29-1)29b	--	1,275	--	5,760	Coconino Sandstone	--	--	--	Anita No. 1 well. L.
(A-29-1)29de	4-58	1,130	--	5,775	Hermit Shale	1,020	4-58	0.5	Anita No. 2 well. L.
(A-29-2)16	1904	514	--	6,450	Toroweap Formation	500	1904	--	Anita Copper Co. Shaft.
(A-30-2)8a1	10-68	600	--	6,500	Toroweap Formation	430	10-68	<0.1	Gray Dick Drill Hole No. 1. Plugged back from 733 feet. L.
(A-30-2)8a2	1-72	540	8	6,500	Toroweap Formation	512	1-72	<0.1	Gray Dick Drill Hole No. 2. Plugged back from 660 feet. L.
(A-30-2)17	1930	1,000	--	6,425	Coconino Sandstone	dry	--	--	Santa Fe - Anita Well. L.
(A-30-2)24a	1966	628	--	6,600	Toroweap Formation	550	10-17-66	1.5	Thurston No. 1 well. Plugged back from 735 feet.
(A-30-2)24a2	1966	650	--	6,600	Toroweap Formation	--	--	0.75	Thurston No. 2 well.
(A-30-2)24bbb	9-66	730	10	6,550	Toroweap Formation	542	10-17-66	0.5	Thurston No. 3 well. L.
(A-30-2)25b	1962	630	--	6,680	Toroweap Formation	--	--	<0.1	McAfee-Meeks No. 2 well. L.
(A-30-2)25c	11-61	623	8	6,670	Toroweap Formation	540 584	11-61 12-63	4.5 --	McAfee-Meeks No. 1 well. Plugged back from 1,400 feet. C. L.

* feet above mean sea level, determined from topographic map

to 188 feet. Records also indicate that these saturated thicknesses decreased with pumpage.

The discharge rate of the wells listed in Table 1 range from less than 0.1 to 4.5 gpm. Records and notes in the files of the Water Resources Division, U.S. Geological Survey, Flagstaff, Arizona, suggest that the larger discharge rates were excessive.

SPRINGS

Records are available for four large springs which occur in canyons tributary to the south side of the Grand Canyon. These records are summarized in Table 2. These springs yield water from the regional Redwall-Temple Butte-Muav aquifer.

THE AQUIFER SYSTEM

Water enters the Paleozoic rock aquifer system via infiltration from ephemeral stream-flow resulting from storms and snowmelt. The greatest amount of precipitation occurs in the month of August, and may occasionally be sufficient to cause surface runoff. Stream-flow is reported to be most common during the early spring and is derived from snowmelt. Metzger (1961) indicates that recharge on the Coconino Plateau in the vicinity of the south rim of the Grand Canyon may be in the range of 0.01 to 0.04 cubic feet per second per square mile. Inspection of records for water level in wells indicates that the general direction of groundwater movement in the Moqui-Tusayan area is toward the south and west in rough correspondence with the regional dip of the Paleozoic strata.

Table 2. DATA FOR LARGE SPRINGS, MOQUI-TUSAYAN AREA, COCONINO COUNTY, ARIZONA

<u>Location</u>	<u>Land Surface Altitude*</u>	<u>Source Rock</u>	<u>Discharge (gpm)</u>	<u>Remarks</u>
(A-31-2)7	3,750	Muav Limestone	210	Hermit Springs
(A-31-2)13abb	3,740	Muav Limestone	300	Indian Garden Springs
(A-32-3)31b	3,165	Muav Limestone	42,000	Blue Spring
(B-33-4)25	3,250	Redwall Limestone	<u>29,000</u>	Havasus Springs

Total Discharge (rounded) 71,500 gallons per minute
160 cubic feet per second

* feet above mean sea level, determined from topographic map

MOQUI WELLS

The five Moqui wells were inspected and measured on May 25, 1977. Two of these wells are recorded in the files of the Water Resources Division, U.S. Geological Survey, Flagstaff, Arizona, in McGavock (1968), and on Table 1 of this report as McAfee-Meeks No. 1 and No. 2 wells. The locations of the wells are shown on Figure 2. Drillers logs are available for the McAfee-Meeks No. 1 well. The five wells are discussed individually as follows:

McAFEE-MEEKS NO. 2 WELL: This well is located 55 feet west from the power pole adjacent to a large yellow water storage tank. The well appears to be equipped at present with a submersible pump and discharge line; however, vandalism to the electrical controls at the surface has occurred and the pumping equipment is inoperable. Field measurements indicate an eight inch casing which projects six inches above land surface for this well. Measurements with an electric water-level sounder indicate the well is presently open to a depth of 522 feet. No water was encountered to this depth.

Records do not indicate the depth to water level in this well; however, an original water level of 550 feet is estimated and it is probable that the pump is set at a greater depth. Caving of the wall rocks in the well is believed to have prevented the sounder from reaching water level. If the hole has caved, the pump may be locked in place and the well probably cannot be rehabilitated.

FIRST NON-RECORDED WELL: This well is located 41 feet west from the power pole adjacent to the yellow water tank. The well

MOQUI

n.

NORTH



Scale

1 inch = 2,000 feet

TUSAYAN

State Highway 64

- Third Non-recorded Well
- McAfee-Meeks No. 1 Well
- Second Non-recorded Well
- First Non-recorded Well
- McAfee-Meeks No. 2 Well

FIGURE 2

LOCATION OF MOQUI WELLS

is not presently equipped. An eight inch casing which projected one foot above land surface was measured in the field. The well is caved and filled with rock and soil, and could be probed only to a depth of 41 feet.

Interviews with local individuals indicate that this well may have been the original McAfee-Meeks No. 2 well and was dynamited in an attempt to increase the yield; however, after the explosion the well collapsed and was abandoned.

SECOND NON-RECORDED WELL: This well is located approximately 150 feet north of the yellow water tank. The well is not presently equipped. Field measurements show a nine inch corrugated pipe casing which projects three feet above land surface. The well is partly filled with rock and soil and could be probed only to a depth of 18 feet.

McAFEE-MEEKS NO. 1 WELL: This well is located several hundred feet south of the yellow water tank and 28 feet west of the tree on which the electrical control box for this well is mounted. The well appears to be equipped at present with a submersible pump and discharge line; however, vandalism to the electrical controls at the surface has occurred, and the pumping equipment is inoperable. Records and field measurements indicate an eight inch casing which projects six inches above land surface. Measurements with the electric sounder indicate the well is presently open to a depth of 479 feet. There was no indication of water at this depth.

Because records indicate that the depth to water level in this well was 540 feet in 1961 and 584 feet in 1963, it is probable that the pump is set at a greater depth and that caving of the wall rocks in the well prevented the sounder from reaching water level. If the hole has caved, the pump is probably locked in place and the well cannot be rehabilitated.

THIRD NON-RECORDED WELL: This well is located several hundred feet south of the yellow water tank and 83 feet north of the tree on which the electrical control box is mounted. The well appears to have been equipped with a submersible pump and discharge line, but the well appears to have caved and been partially filled with rock and soil which has locked the pump in place. Field measurements show a six inch casing whose top is flush with the ground level. The well was plumbed to a depth of 481 feet at which obstructions prevented further penetration. The discharge line was plumbed to a depth of 600 feet at which depth the top of the pump may have been encountered. No indication of water was found, although examination of records for McAfee-Meeks No. 1 well suggests that a water level of approximately 540 feet below land surface may have been encountered at the time of drilling.

It appears that the pump in this well is locked in place, and the well probably cannot be rehabilitated. Attempts at previous rehabilitation are suggested by damage to the upper part of the discharge line. This well may have been the original McAfee-Meeks No. 1 well.

ANALYSIS: Although the pumping equipment is probably locked into position by caving in the wells and although records and a 600 foot measurement in the discharge line of the third non-recorded well suggest progressive decline of water levels, attempts could be made to produce small amounts of water from the two equipped wells. If the pumps can be pulled from wells (A-30-2)25b and (A-30-2)25c, the pumping equipment could be inspected and the wells cleaned by bailing and water level measurements made. If small amounts of water are found below the 600 foot level, the pumps could then be reset and the wells placed into intermittent low-yield operation at an aggregate pump rate of less than one gallon per minute.

Approximate costs for well rehabilitation attempts at the Moqui wells are as follows:

Move-in	\$400.00
Pump removal (Minimum of 3 hours @ \$100.00/hour)	300.00
Bailing time (Minimum of 4 hours @ \$100.00/hour)	400.00
Resetting pump (3 hours @ \$100.00/hour)	300.00
Total	\$1,400.00

These costs are a minimum estimate of total costs because:

1. Pump removal is probably not possible.
2. If pump removal can be accomplished, the time required for removal may be much longer than indicated.
3. If caving occurs during bailing, much longer bailing times may be required.

Because the costs for possible rehabilitation are high and because the potential for water production is low, it is recommended that the Moqui wells be abandoned.