2.0 Delineation Report

This Delineation Report includes four wells in the Moab well field, which is located in and near the Moab Golf Course. The Moab well field is located southeast of the town of Moab, Grand County, Utah (fig. 1). The wells included in this delineation report are Well #6 (Utah Division of Drinking Water {DDW} source no. 07), Well #10 (Robertson, DDW no. 10), Well #7 (DDW no. 08) and Well #4. Wells #6 and #10 are currently considered the main well sources for Moab City. Well #7 is included because it is still listed as part of the Moab water system. Well #4 is included because it could be used in the future; however, there is presently no pump in this well. Two wells at this location, Well #4 and #4A, are approximately 34 feet apart. Well #4A is newer and deeper than Well #4; however, there are problems with this well pumping too much sand (L. Johnson, personal communication, 1991). Well #5 was a public water source in the past, but has been disconnected from the water system. The golf course uses water from Grand County Water Conservancy District for watering the golf course, and uses Well #5 only occasionally. Because it is only used occasionally, Well #5 was not included as an interfering well in the ground-water modeling.

The Utah Drinking Water Source Protection (DWSP) Rule (R309-113, Utah Administrative Code) allows two different methods for delineation of protection zones. The Preferred Delineation Procedure consists of protection zones based on ground-water travel time or hydrogeologic boundaries. The protection zones in this report are based on the Preferred Delineation Procedure. The other method is the Optional Two-mile Radius Delineation Procedure.

2.1 Geologic Data

Moab is located in southeastern Utah in the Colorado Plateau physiographic province. The Moab well field is located along the northeast side of Spanish Valley, in Grand County. The Navajo Sandstone is exposed in the area surrounding the wells, and is overlain by thin deposits of eolian sand (Steiger and Susong, 1997; and Doelling, 1993). Beneath the Navajo Sandstone are the Kayenta Formation and Wingate Sandstone. These three formations form the Glen Canyon Group. The Kayenta Formation and Wingate Sandstone are exposed in canyons east of the Moab well field (Doelling, 1993).

The Moab well field and area east of the wells is included in the area called the Mill Creek-Spanish Valley area as named and outlined by Blanchard (1990). In this area the Jurassic-age Navajo Sandstone is light reddish-orange, fine- to medium-grained sandstone which displays eolian cross-bedding. It forms domes and cliffs, and is 0-550 feet thick. Underlying the Navajo Sandstone is sandstone of the Kayenta Formation. The Kayenta is fine to coarse-grained, and forms reddish-brown ledges. The Kayenta Formation is 100 to 300 feet thick in this area. Underlying the Kayenta is the massive, cliff-forming Wingate Sandstone. The Wingate consists of orange-brown, fine-grained sandstone which forms cliffs. The Wingate Sandstone is 250-450 feet thick (Doelling, 1993). The Navajo Sandstone, Kayenta Formation and Wingate Sandstone are combined in the Moab area as the Glen Canyon aquifer (Blanchard, 1990).

The general geology of the Mill Creek-Spanish Valley area is shown in figures 2 and 3. The Mill Creek-Spanish Valley area appears to encompass the recharge area for the aquifer

2.3 Aquifer Data

In the Mill Creek–Spanish Valley area, the Navajo Sandstone, Kayenta Formation, and Wingate Sandstone appear to be in hydraulic connection, and these three stratigraphic units make up the Glen Canyon aquifer. The Kayenta Formation is normally finer-grained than the Navajo or Wingate, thus separating the two aquifers. The Kayenta Formation is mostly sandstone in the Mill Creek-Spanish Valley area and all three formations are highly fractured, allowing them to form one aquifer (Blanchard, 1990). All of the wells in the Moab well field are completed in the Glen Canyon aquifer.

The La Sal Mountains, southeast of the Mill Creek-Spanish Valley area, are a regional source of recharge for the aquifers in the Moab area. The major source of recharge to the Glen Canyon aquifer is precipitation on the exposed Navajo Sandstone and on overlying unconsolidated deposits. Average annual precipitation in the recharge area east of the Moab well field ranges from 7.5 inches near the wells to 13 inches in the higher elevations near the La Sal Mountains (Steiger and Susong, 1997). Eolian sand deposits cover large areas of the bedrock formations (Figure 3 of Steiger and Susong, 1997). These overlying deposits provide materials where precipitation can rapidly infiltrate before recharging the bedrock aquifer (Steiger and Susong, 1997).

Mill Creek flows through the recharge area for these wells, approximately 3000 to 5000 feet east of the wells. Mill Creek also provides recharge to the ground water in the area east of the well field. Mill Creek is a gaining stream in the eastern part of the Mill Creek-Spanish Valley area, then recharges water to the aquifer in its lower reaches where it flows northwest parallel to Spanish Valley. The reach of Mill Creek east of the well field was recharging about 650 ac-ft/year to the aquifer during October 1985 (Blanchard, 1990).

Hydraulic gradient: The hydraulic gradient in the area of the well field was determined using two different methods. The approximate potentiometric surface map (fig. 5) yields a gradient value of 0.0302. Another approximation of the hydraulic gradient was determined by comparing the water level in Well #6 and the elevation of Mill Creek east of the well, which yields a value of 0.0273. This range of hydraulic gradient is used in the delineation calculations.

Ground water flow direction: The general direction of ground water movement in the Moab area is to the northwest, from the La Sal mountains toward the Colorado River (fig. 6). In the Mill Creek-Spanish Valley area, the ground-water flow direction is approximately west to S70°W in the area of the well field, as determined from the approximate potentiometric surface map (fig. 4).

Aquifer porosity: There is both primary and secondary porosity in the Glen Canyon aquifer. The effective porosity of the Glen Canyon aquifer in this area is approximately 19% (Freethey and Cordy, 1991). Secondary porosity is from faults and the extensive fractures along the northwest edge of the Moab Valley anticline. To be conservative, a value of 15% is used for effective porosity in this delineation work.

Saturated thickness: Saturated thickness of the Navajo-Nugget aquifer (equivalent to the Glen Canyon aquifer) is between 500 and 1,000 feet in the Moab area (Freethey and Cordy, 1991). Well #9, approximately 2200 feet southeast of Well #4, penetrates the aquifer 450 feet, and appears to be completely within the Glen Canyon aquifer. Thickness of the producing aquifer was estimated by determining the vertical length of the wells that is open to the aquifer. Well #6 is perforated over an interval of 73 feet (105-178 feet below ground surface), Well #10 for a distance of 100 feet (180-280 feet bgs). and Well #7 is perforated for a distance of 98 feet (105-203 feet bgs). For modeling the ground-water flow. an aquifer thickness of 100 feet was used for zones two and three. and 100 to 180 feet for zone four. The value of 180 feet was selected for zone four based on water levels and total depth of Well #10 and Well #6. and choosing a conservative value for aquifer thickness at distances more than about one mile from the Moab well field. The saturated aquifer thickness penetrated by the wells is 130 feet in Well #6, 180 feet in Well #10. over 300 feet in Well #7. Well #9 indicates a saturated thickness of over 400 feet.

Transmissivity and hydraulic conductivity: The U.S. Geological Survey conducted an eight-day aquifer test using Well #6 as the pumping well and seven wells in the area as observation wells. The drawdown data obtained from this test did not fit the standard drawdown curves. Test results did indicate impermeable boundaries near some of the wells. USGS personnel concluded that the Glen Canyon aquifer in this area is structurally complex. and that aquifer characteristics in the well field can vary significantly through the area (Blanchard. 1990). Based on a previous pumping test conducted in October 1978. there is some degree of hydraulic connection between Wells #6. #7. and #10 (Don Robinson. notes in Moab City files dated November 3. 1978).

Because hydraulic conductivity could not be determined from the eight-day aquifer test conducted by the U.S. Geological Survey. as discussed above. other methods had to be used to estimate aquifer transmissivity. Freethey and Cordy (1991) report a hydraulic conductivity value of 1 ft/d from laboratory tests. but this probably does not account for flow through fractures. Sumsion (1971) estimated the transmissivity of the Moab well field area to be about 6.000 ft^2/d. and that the less-disturbed Navajo Sandstone northeast of the well field was about 1.200-1.500 ft^2/day.

The specific capacity of 14 wells in the Mill Creek-Pack Creek area was reported by Blanchard (1990) (fig.7). Using the reported median value for specific capacity of 12.5 gpm/ft for the Moab golf course area. and the method of Heath (1989) for estimating transmissivity from specific capacity, the transmissivity is 3750 ft^2/d.

$T = 300 \times (Q/s)$. where T = transmissivity, ft^2/d
Q = pumping rate, gpm
S = drawdown, ft

Using the same median value for specific capacity and the approximation method of Pettyjohn (1992), the estimated transmissivity is 2590 ft^2/day.

$T = 1550 \times (Q/s)$. where T = transmissivity, gpm/ft

A range of transmissivity from 2590 ft^2/d to 3750 ft^2/d was used for delineating the protection zones. This range of values appears to be representative of the Glen Canyon aquifer in the Mill Creek-Spanish Valley area. The higher value was used to calculate Zones two and three, because fracturing appears to be more closely spaced in the general area near the golf course than in the area one-half mile or more east of the wells. The lower value was used to calculate Zone four, simulating ground water flow farther from the well field. This range of transmissivity and aquifer thickness yields a range in hydraulic conductivity from 14.4 ft/d to 37.5 ft/d.

2.4 Hydrogeologic Methods and Calculations

Ground-water modeling along with hydrogeologic mapping was used to delineate the protection zones for the Moab well field. Hydrogeologic mapping is normally the best method for delineation of protection zones in fractured rock aquifers. However, in this case, the Glen Canyon aquifer extends to the east of the Moab well field for several miles, and ground-water flow boundaries could not be determined by surface geologic mapping. Flow boundaries, if present, could be used to delineate the protection zones.

Because of the lack of ground-water flow boundaries and the effect of interference from other pumping wells, ground-water flow modeling was used to try to approximate travel distances and size of the protection zones. The standard ground-water flow equations developed for porous media may be useful in fractured rock aquifers where the fractures are numerous, and fractures occur at a small scale when compared to the scale of the protection zones (Bradbury and others, 1991). Fractures are pervasive in the Glen Canyon aquifer east of the Moab well field, and the highly fractured area of Steiger and Susong (1997) extends along the east side of Spanish Valley, which is the recharge area for the Moab well field. The ground-water flow direction is oblique to the direction of major fractures (Blanchard, 1990) indicating a high degree of interconnection across the fractures.

A two-dimensional finite difference ground water flow model called Flowpath II was first used in an attempt to model the ground-water flow and to model the creek as a partially penetrating boundary. However, because of the limited hydrogeologic data available for the Glen Canyon aquifer east of the Moab well field, this model did not serve as a reasonable method to approximate the flow system. So a simpler ground-water model, called WHPA, was utilized. WHPA was designed for more simple aquifer environments, and thus requires less input data. WHPA is a semi-analytical model for delineating wellhead protection zones, and was developed by Blandford and Huyakorn (1991) for the U.S. Environmental Protection Agency. The RESSQC module of WHPA is modified from the original RESSQ code developed by Javandel and others (1984). This module was selected for the Moab well field because it can calculate protection zones for multiple wells in the same aquifer, and the effects of well interference are incorporated.

To account for uncertainties in the aquifer properties, the model was run multiple times using different combinations of hydraulic gradient, transmissivity, and flow direction (table 2). It was assumed that all four wells were pumping in all of the model runs. The four wells were treated as a well field, and the protection zones were combined because the wells significantly affect the protection zones of nearby wells. Through multiple model runs, the longest and the widest zones that are reasonable for the listed aquifer parameters were calculated (see appendix). Results of the different model runs were then manually combined as the final protection zones (fig. 8).

Table 2. – Aquifer parameters used in the ground water model.

Hydraulic Gradient	0.0273 to 0.0302
Flow Direction	Generally west, northwest to S70°W
Effective Porosity	15%
Effective Saturated Thickness	100 feet
Transmissivity	2590 to 3750 ft²/d

2.5 Map Showing Boundaries of the DWSP Zones:

The map of protection zones is figure 8. The up-gradient and down-gradient distances in Table 3 are measured from Well #6.

Table 3. – Written description of protection zones.

	Upgradient (feet)	Orientation	Downgradient (feet)	Maximum Width (feet)
Zone 1	100-foot radius around each well (not shown on map)			
Zone 2	3700	East from well field	750	5300
Zone 3	10.700	East from well field	750	12.500
Zone 4	26.000	East from well field	750	24.000

2.6 Unprotected Aquifer Classification

Wells in the Moab well field are producing from an unprotected aquifer. as defined in the Drinking Water Source Protection Rule.

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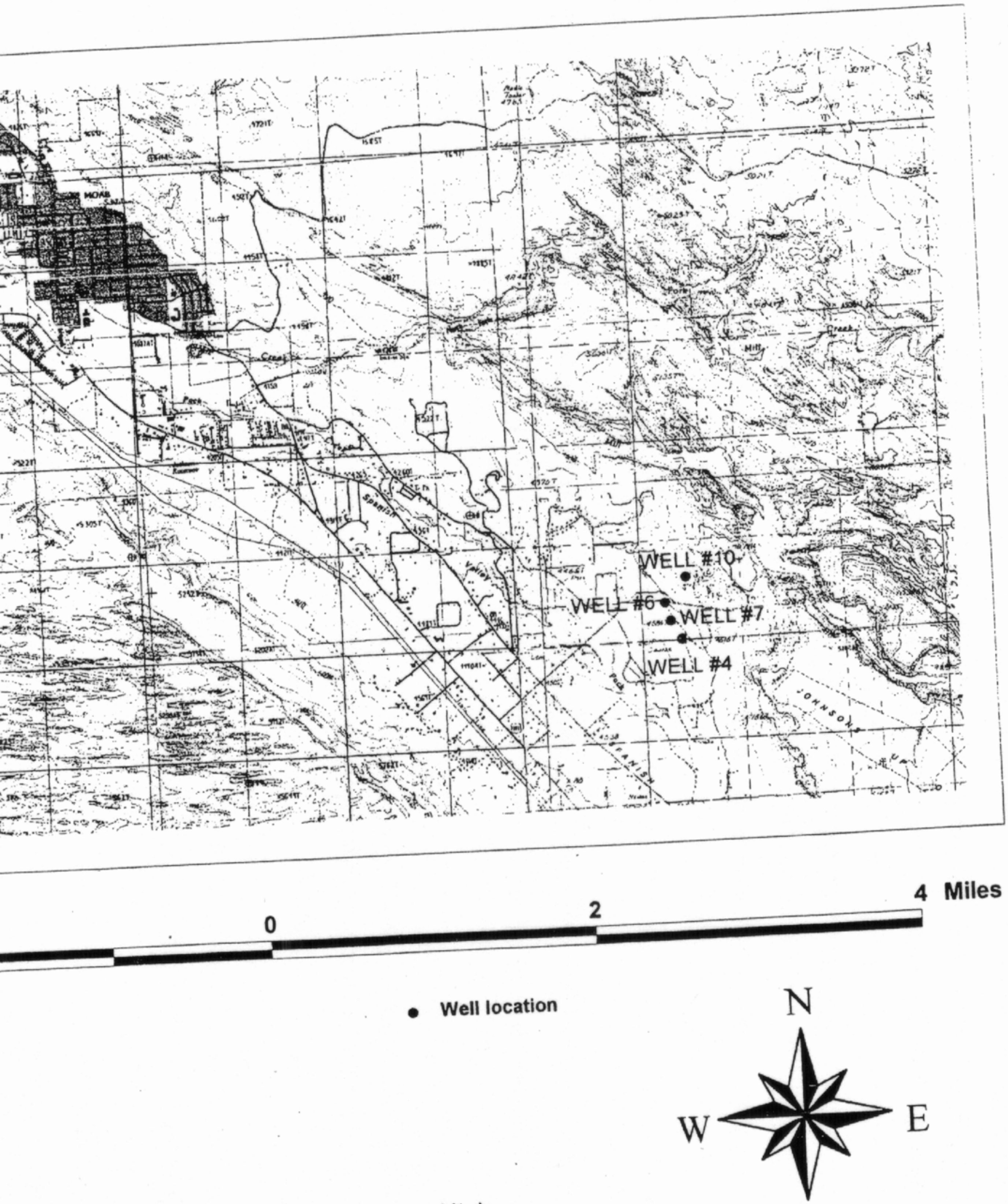

Figure 1. Moab well field, Grand County, Utah.

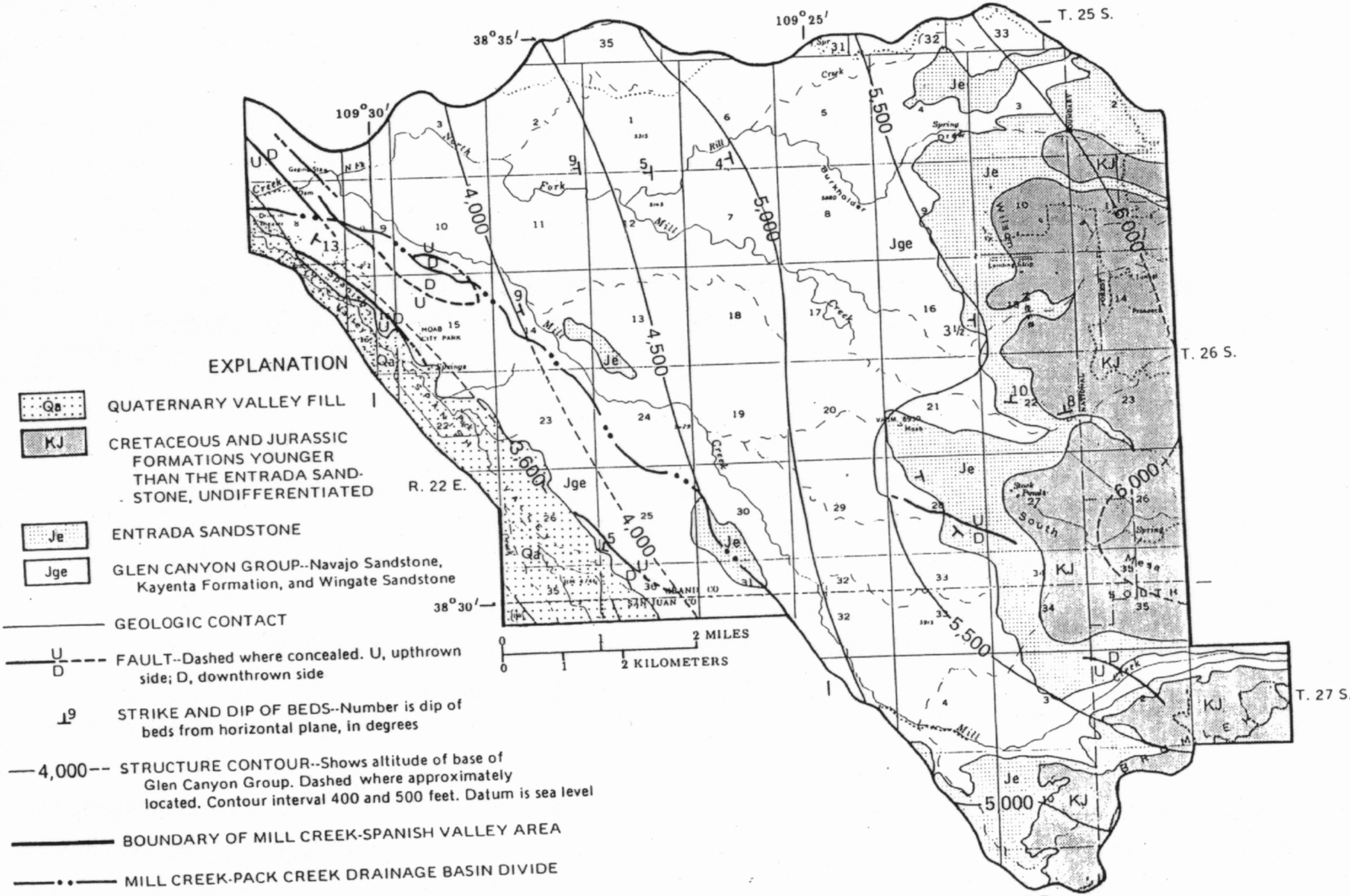

Figure 2. - Geology of the Mill Creek-Spanish Valley area. (Blanchard, 1990, Figure 18)

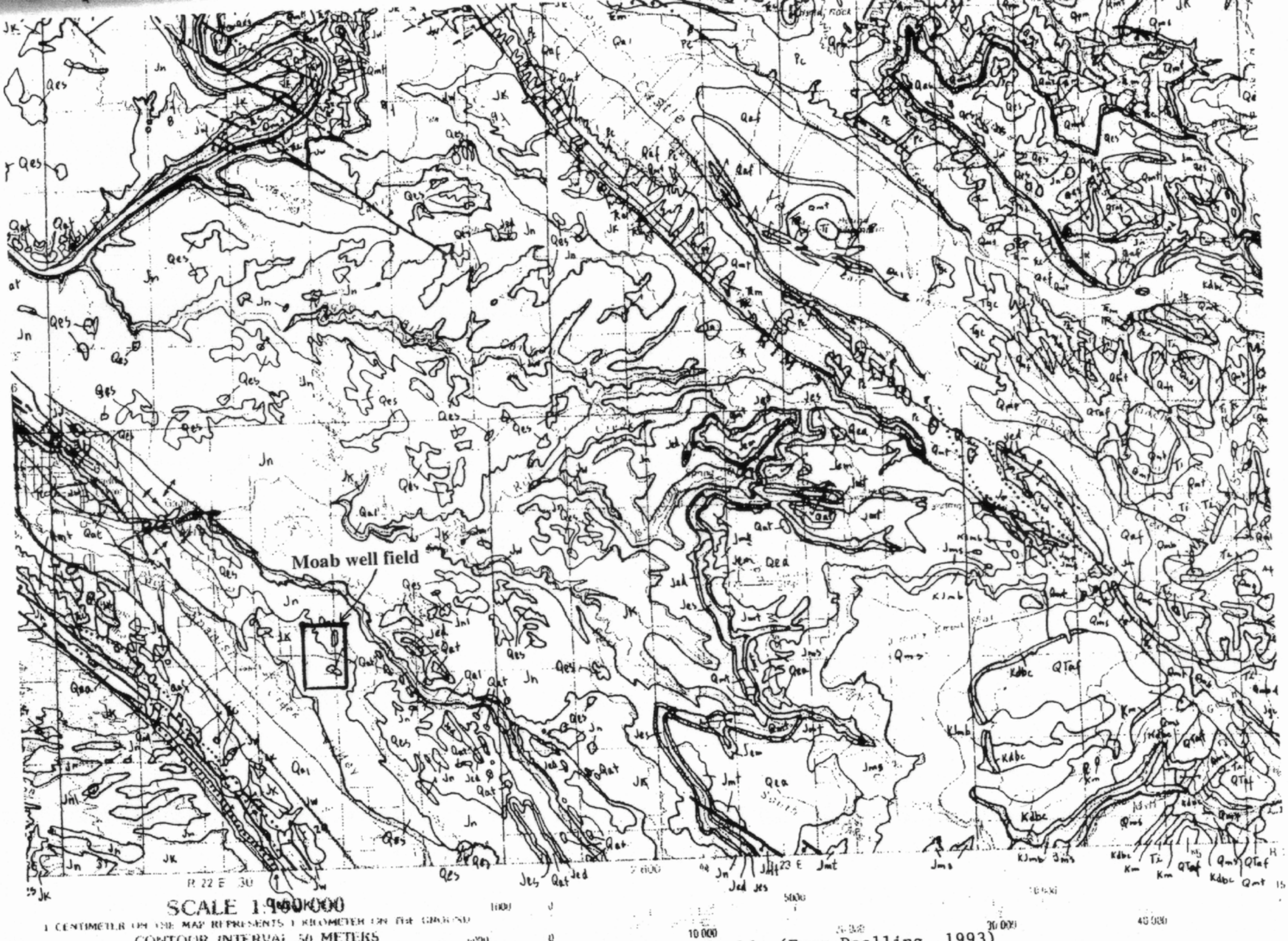

Figure 3. - Geology of the area east of the Moab well field. (From Doelling, 1993)

Figure 3. – Description of selected map units. modified from Doelling (1993).

Qal Alluvium – Sand. silt. clay. granules. pebbles. and sparse cobbles: unconsolidated: adjacent to more active stream courses. Thickness ranges widely; commonly less than 30 feet.

Qat Alluvial terrace deposits – Cobbles. granules. pebbles. sand. silt. and clay; adjacent to. and higher than river. stream. and larger ephemeral stream courses: generally contain clasts from distant upstream sources (exotic metamorphic. igneous. and chert clasts. Thickness commonly 15 feet or less.

Qea Mixed eolian and alluvial deposits – Sand and silt of eolian origin interspersed with silt. sand. and gravel of fluvial origin; generally dominated by eolian deposits. Thickness 30 feet or less.

Qes Eolian sand deposits – Sand and silt: well-sorted: deposited as sheets or poorly developed dunes. Thickness 25 feet or less.

Qms Slumps and landslides – Coherent. broken. masses of muddy bedrock units that have moved downslope by gravity.

Je Entrada Sandstone. undivided – Middle Jurassic.

Jgc Glen Canyon Group – Exposures of formations described below where found in small areas or where they cannot be suitably differentiated.

Jn Navajo Sandstone – Mostly light-hued sandstone; fine-to medium-grained; displays eolian cross beds; massive; forms cliffs. domes. and rounded knolls; locally contains thin. hard. gray limestone beds (Jnl). 0-550 feet thick. pinches out to northeast. Early Jurassic.

Jk Kayenta Formation – Reddish-brown. lavender-gray sandstone; contains local white and dark-brown beds, intraformational conglomerate. and limestone; fine to coarse grained; resistant. forming thick ledges. 100 to 330 feet thick. Early Jurassic.

Jw Wingate Sandstone – Orange-brown. dark-brown-weathering sandstone; fine grained; massive; forms vertical cliff along canyon walls. 250 to 450 feet thick. Early Jurassic.

Figure 4. - Fractures in the Navajo Sandstone. Moab Golf Course is in the southwest part of the aerial photograph. (NAPP photography enlarged from 1:40,000 to 1:24,000)

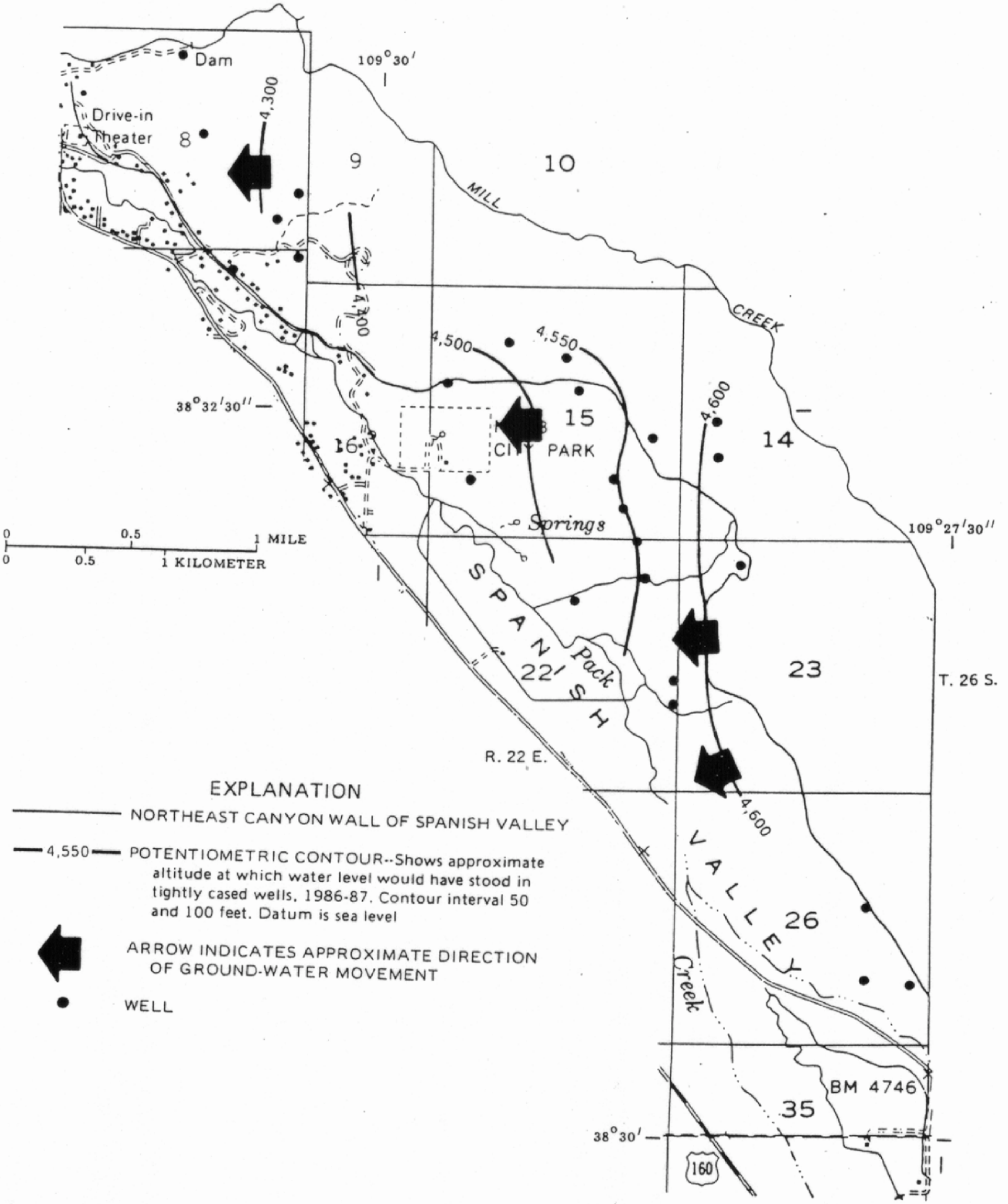

Figure 5. - Approximate potentiometric surface and direction of movement of water in the Glen Canyon aquifer in the Mill Creek-Pack Creek area, 1986-87. (Blanchard, 1990, Figure 19)

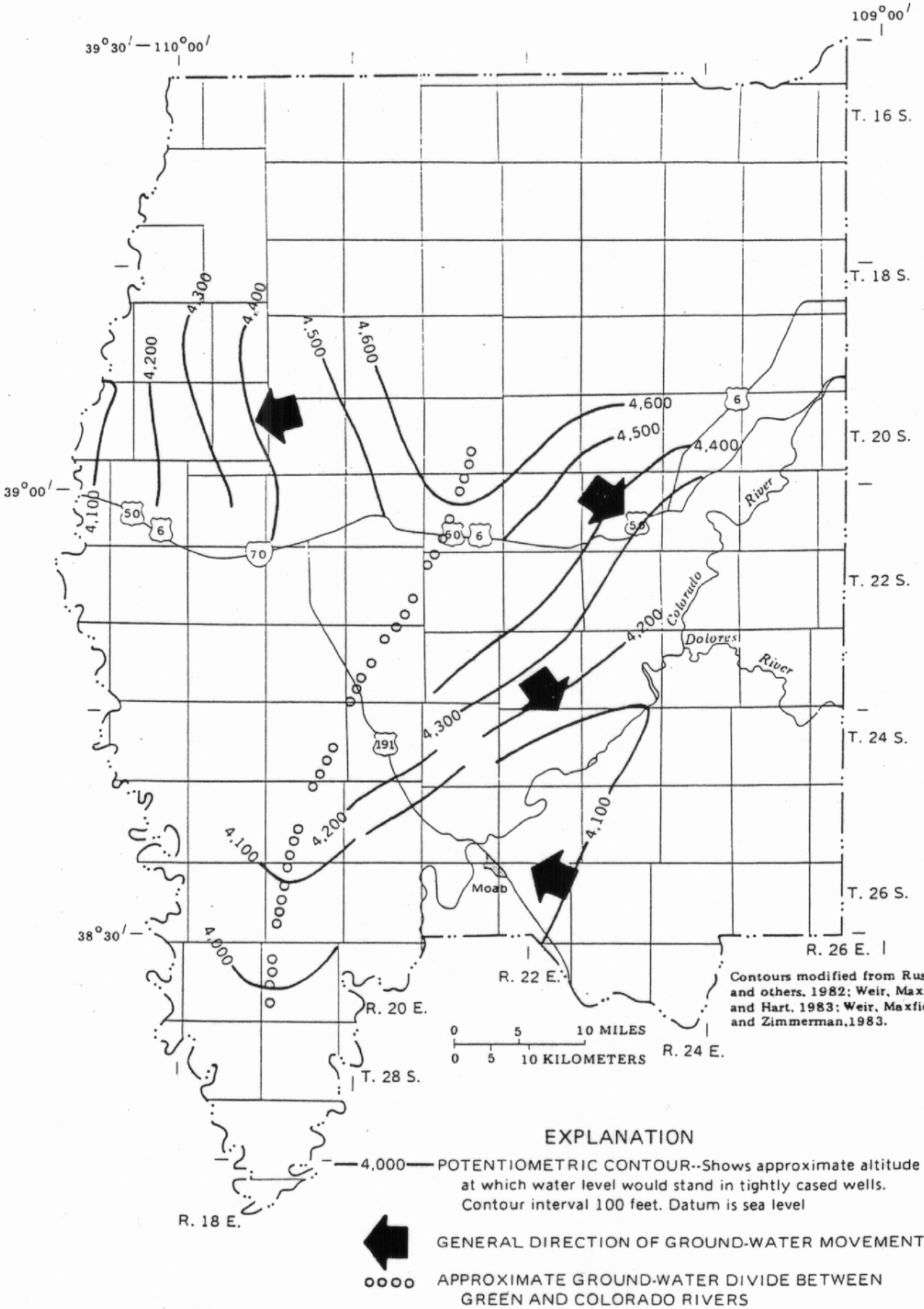

Figure 6. - Approximate potentiometric surface and general direction of movement of water in the upper ground-water system. (Blanchard, 1990, Figure 9)

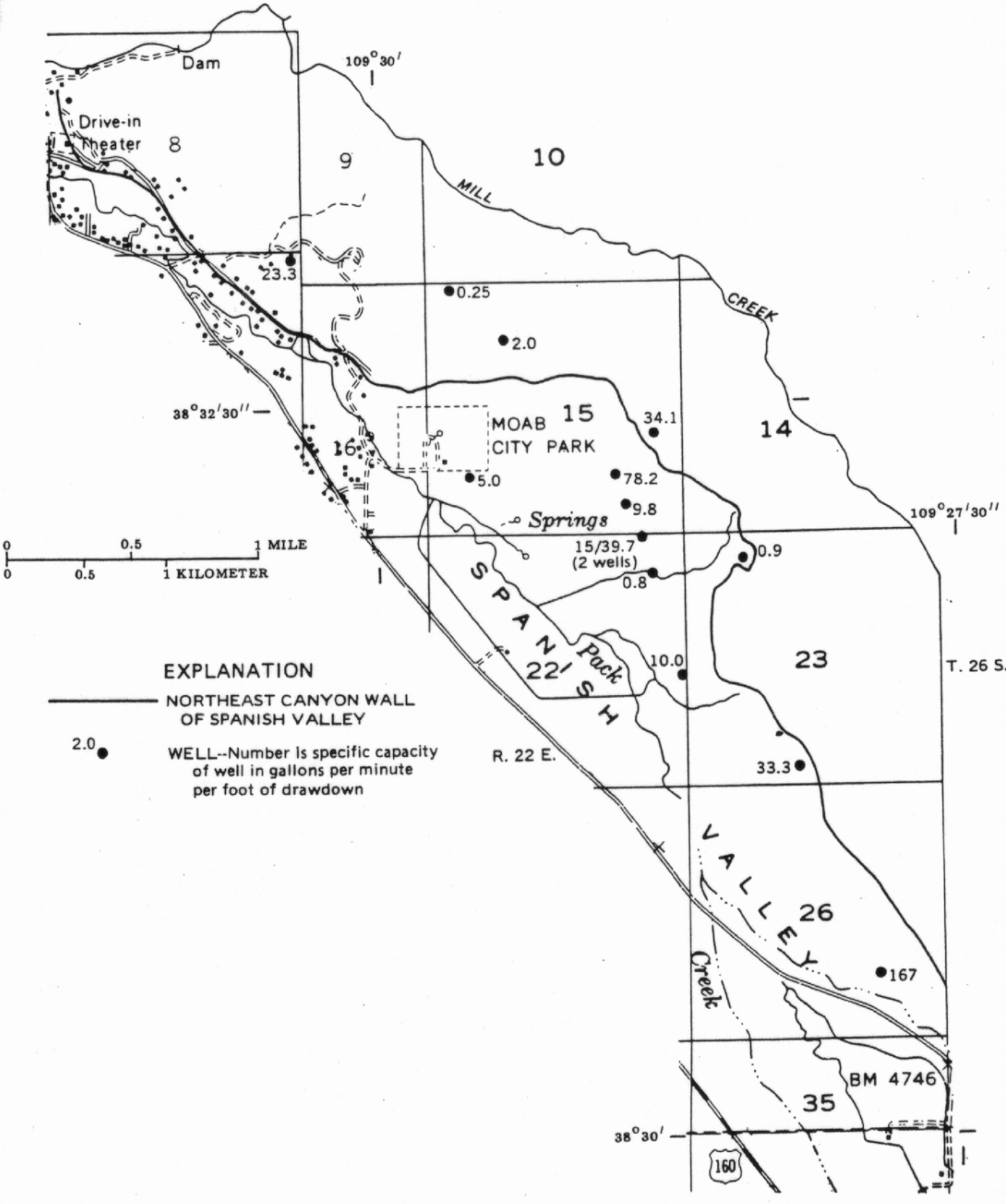

Figure 7. – Specific capacity of wells completed in the Glen Canyon aquifer in the Mill Creek-Pack Creek area. (Blanchard, 1990, Figure 21)