

**Groundwater Availability in Moab,
Spanish Valley, Utah**

**Department of Civil and Environmental Engineering
Brigham Young University**

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April 2000**

COLLEGE OF
ENGINEERING AND TECHNOLOGY
BRIGHAM YOUNG UNIVERSITY
PROVO, UTAH

**GROUNDWATER AVAILABILITY IN MOAB,
SPANISH VALLEY, UTAH**

A PROJECT PRESENTED TO THE
DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING
BRIGHAM YOUNG UNIVERSITY

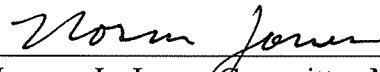
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
MASTER OF SCIENCE

TIMOTHY RYAN KOVACS
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This project, by Timothy Ryan Kovacs, is accepted in its present form by the Department of Civil and Environmental Engineering of Brigham Young University as satisfying the project requirement for the degree Master of Science.



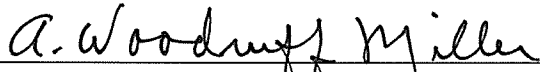
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Introduction

The Grand County Water and Sewer Service Agency (GCWSSA), which supplies water to the unincorporated area of Spanish Valley southeast of Moab, Utah, has acquired water rights for 4,234 ac*ft of water per year in addition to the water that it currently supplies (Pierson, 2000). The additional water rights will be used to meet future demand for water as more development occurs in the area. The GCWSSA is currently searching for sources from which this water can be drawn. As part of the search, it is necessary to know how much of the additional water can be withdrawn from groundwater without affecting the water quality in the area. To help determine how much of the water can be withdrawn from groundwater, a three-dimensional finite difference model of the area was developed using GMS and MODFLOW. A particle-tracking model to help determine the source of that water was then developed using GMS and MODPATH.

Background Information

Geology

Spanish Valley (shown in Figure 1) is a northwest–southeast trending valley opening to the Colorado River near the Utah–Colorado border in southeastern Utah. The valley is the result of a salt collapse beneath an anticline. The main geologic features in the area are the Glen Canyon Group sandstones and the La Sal Mountains (Eisinger and Lowe, 1999). The Glen Canyon Group is composed of the Wingate, Kayenta and Navajo sandstone units. These sandstone units form the steep walls on each side of Spanish Valley, as well as the domes and dendritic canyons for which Moab and the surrounding area is famous. The La Sal Mountains are the result of igneous intrusive rocks being

uncovered by erosion of the surrounding sandstone. They rise high above the sandstone formations, with peaks greater than 12,000 feet (Sumsion, 1971).

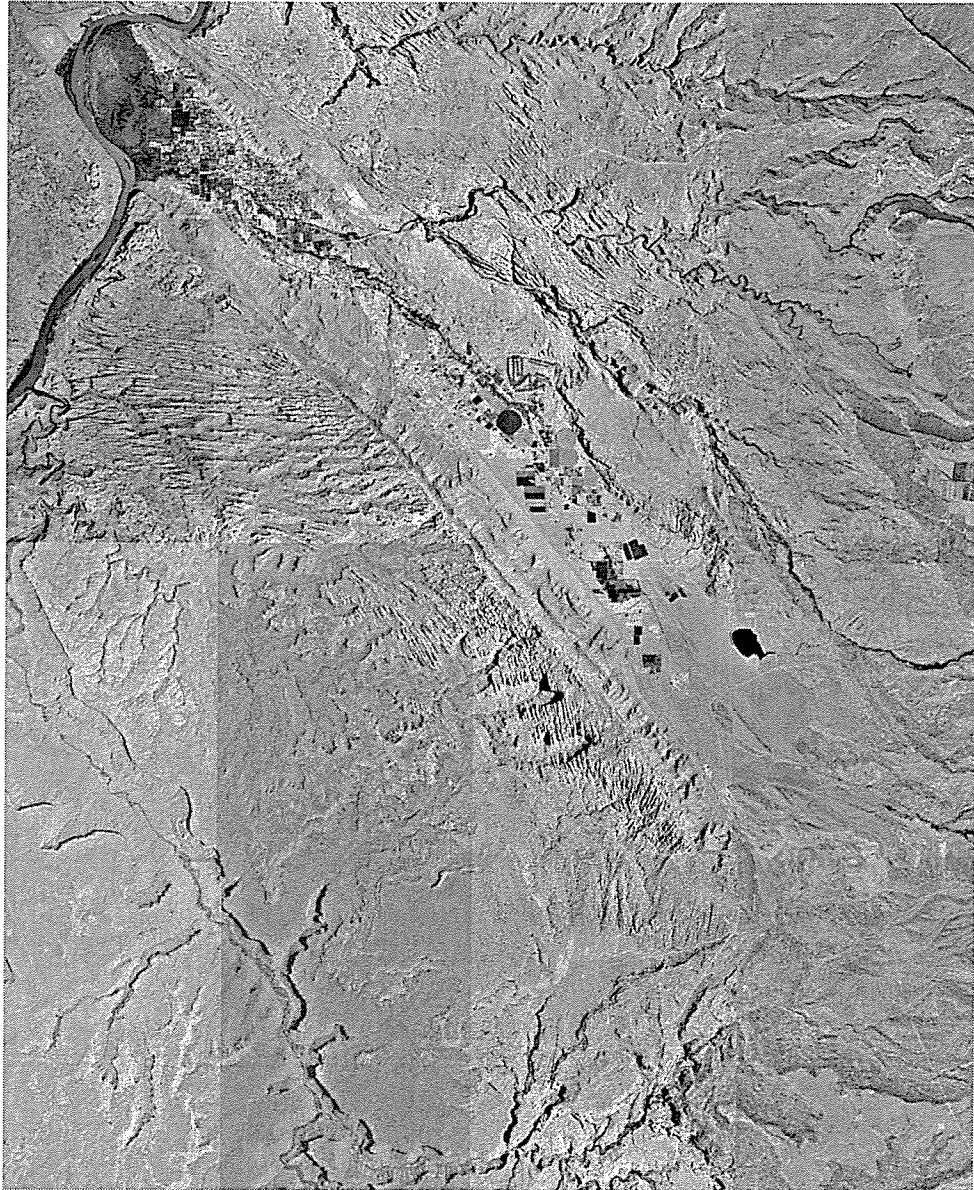


Figure 1: Aerial photo of Spanish Valley

The valley fill, predominantly composed of stream alluvium and alluvial fan deposits from Mill and Pack Creeks, is as deep as 400 feet in the northwestern end of the valley near the Colorado River (Eisinger and Lowe, 12). The average thickness of saturated fill

in the valley is about 70 feet (Sumsion, 22). As sediments are carried into the valley by the creeks, the coarser particles are deposited first in the southeastern part of the valley. The smaller sediment particles are carried farther and deposited toward the northwestern end of the valley.

Precipitation

Average annual precipitation in the Spanish Valley area ranges from about 8 inches along the Colorado River to about 20 inches at the base of the La Sal Mountains (Blanchard, 1990), with a weighted average annual precipitation in the area of about 15 inches (Sumsion, 1971). Most of the precipitation in the Spanish Valley area is lost to evapotranspiration. An average of only 0.25 inches of the precipitation on the valley infiltrates down and recharges the groundwater (Eychaner, 1977).

Summer precipitation is usually in the form of thunderstorms, which are localized, intense, and short-lived. There is little time for precipitation from such storms to infiltrate and recharge the groundwater, and most of it becomes evapotranspiration or runoff. Winter precipitation is less localized, less intense, and of longer duration. At higher altitudes, especially in the La Sal Mountains, it usually is in the form of snow. The gradual melting of the snow allows more time for precipitation to infiltrate and recharge the groundwater, especially during spring melting of the winter snowpack at higher altitudes (Blanchard, 1990).

Surface Water

The Colorado River is the major perennial stream in the Spanish Valley area. It flows along the northwestern end of the valley, and all water in the area drains toward it. The wetland at the northwest end of the valley is occasionally flooded by high water in

the Colorado River, but water generally discharges from the valley into the wetland and river.

Mill and Pack Creeks are also perennial streams. Mill Creek flows east of, and nearly parallel to the axis of Spanish Valley for much of its length, then turns into the valley near the city of Moab. It then flows through Moab and empties into the Colorado River. Pack Creek enters Spanish Valley from the southeast end and flows through the valley until joining Mill Creek just upstream from the wetland. Parts of Pack Creek are dry except during periods of heavy runoff because flow is diverted for irrigation on agricultural land in the middle of the valley (Sumsion, 1971).

Water is diverted from Mill Creek through the Sheley tunnel diversion to a man-made reservoir called Ken's Lake. Water from Ken's Lake is used for irrigation in the agricultural area in the middle of the valley. The lake is located on coarse-grained sediments and is not lined, so water easily infiltrates through the lake bottom and recharges the groundwater.

Aquifers

There are two major aquifers in Spanish Valley – one composed of unconsolidated valley fill deposits, and one in the Glen Canyon Group. The valley fill aquifer is composed mainly of alluvial deposits from Mill and Pack Creeks (Sumsion, 1971). The valley fill aquifer provides water that is used mostly for irrigation, but also for some domestic water supply (Steiger and Susong, 1997).

The three sandstone units of the Glen Canyon Group comprise the Glen Canyon aquifer. The relatively low permeability Kayenta unit separates the Wingate and Navajo units. However, they are considered to be hydraulically connected, especially where they

are highly fractured, as is the case along the eastern side of Spanish Valley (Blanchard, 1990). For this reason, they are treated as one unit in this model.

Recharge

The main source of groundwater recharge in the Spanish Valley area, especially to the Glen Canyon aquifer, is recharge in the La Sal Mountains. The slopes of the mountains are covered in many areas by talus, which readily absorbs snowmelt runoff and precipitation. Much of this water is eventually transmitted to the Glen Canyon aquifer. Recharge to the Glen Canyon aquifer also takes place due to seepage along intermittent and ephemeral streams, as well as from direct infiltration of precipitation where the fractured-rock aquifer crops out (Eisinger and Lowe, 1999).

Recharge is enhanced where the fractured rock is overlain by coarse unconsolidated deposits that are saturated at a depth of more than about 6 feet below the land surface, beyond which the effects of evaporation decrease rapidly (Blanchard, 1990). Several recharge zones in the conceptual model represent such high recharge zones (Steiger and Susong, 1997).

A number of springs discharge from the sides of Spanish Valley, especially from the eastern side. Springs are likely to occur where fractured rock, especially from the Glen Canyon Group, is near the surface. The greatest concentration of springs occurs near the Moab golf course, where there are many outcroppings of fractured Glen Canyon Group sandstones (see Figure 2).

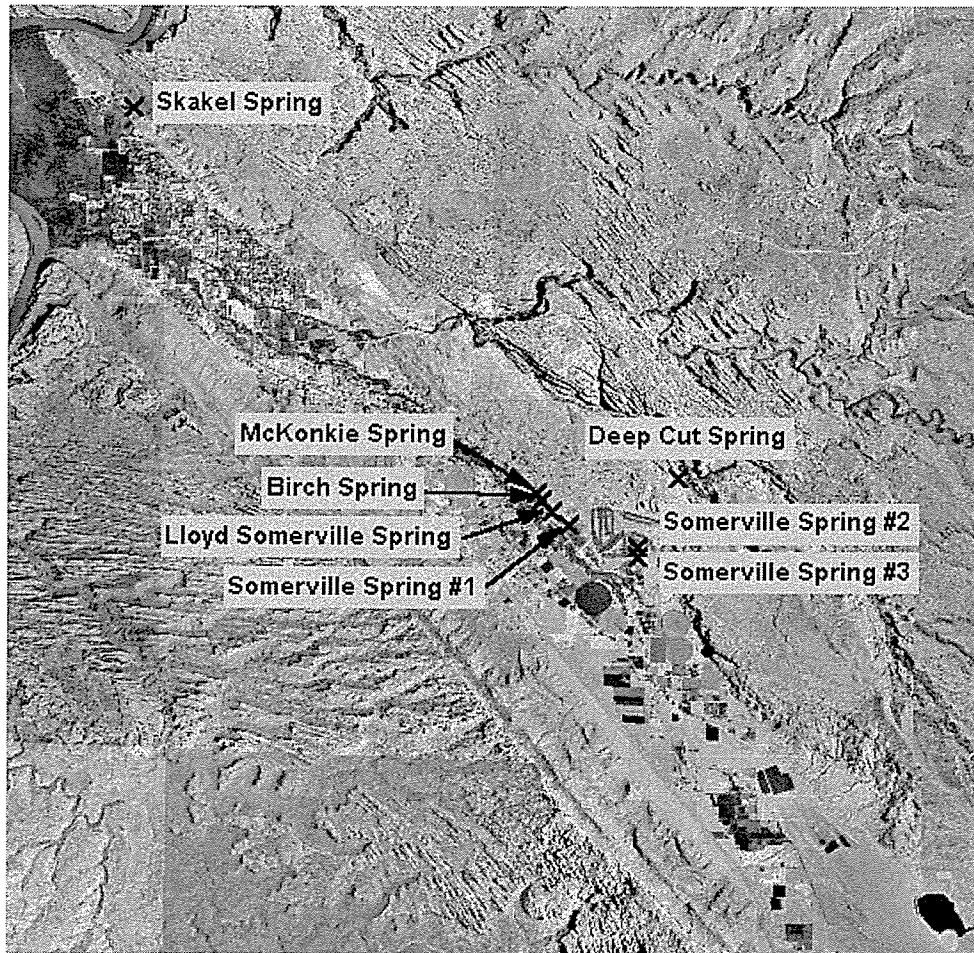


Figure 2: Spring locations along the east side of Spanish Valley

Most of the recharge to the valley fill aquifer is from springs and subsurface flow from the Glen Canyon aquifer, principally from the eastern side of the valley (Sumsion, 1971). Direct precipitation on the valley fill and infiltration of water from Ken's Lake also recharge the valley fill aquifer (Eisinger and Lowe, 1999).

The vast majority of culinary water wells in the valley are located along the eastern side of the valley in a zone of highly fractured rock. This is due to the fact that the water entering from the eastern side is high quality water, meaning that its total dissolved solids concentration is very low. The western side of the valley is underlain by the Paradox salt formation, which contributes to the poor quality of the water. An important

consideration in pumping more water from the eastern side of the valley is that lower quality water from the western side of the valley not be drawn toward the eastern side, compromising the area's water quality.

Water Budget

Hydrologic and hydrogeologic information for Spanish Valley indicates the following water budget for groundwater in Spanish Valley (Sumsion, 1971):

| | <u>ac*ft/yr</u> |
|---|------------------|
| Inflow | |
| Recharge (assumed to be equal to total discharge) | 14,000 |
| Outflow | |
| Groundwater discharge to Colorado River and evapotranspiration in wetland | 11,000 |
| Groundwater withdrawal use | 3,300 |
| Total discharge (rounded) | 14,000 (rounded) |

Sumsion estimates that in the entire Spanish Valley area 14,000 ac*ft/yr discharges from Mill and Pack Creeks into the Colorado River (Sumsion, 1971). However, this includes a length of upper Mill Creek that is not included in this model. At the point where Mill Creek enters the modeled area, it carries approximately 5,200 ac*ft/yr (Blanchard, 1990). Therefore, the two creeks gain a total of about 8,800 ac*ft/yr within the model boundaries. Unfortunately, it is not known how much of that amount is gained from groundwater and how much is from surface runoff. More recent reports on groundwater withdrawal use in the valley indicate that since the time of Sumsion's report, groundwater withdrawal has increased from 3,300 ac*ft/yr to 6400 ac*ft/yr (Moab, 1999; Pierson, 2000).

Water budget information from the Grand County Water and Sewer Service Agency indicates that an average of about 3,300 ac*ft/yr is lost to leakage from the lake (Pierson, 2000). This is recent information that was not included in the published literature on Spanish Valley.

Model Input

Model Grid Geometry

The 3D finite-difference grid for the model consists of two layers. Layer 1 represents the unconsolidated valley fill aquifer and Layer 2 represents the fractured-rock Glen Canyon aquifer.

Layer 1

Top Elevations

Land surface elevations were taken from contours on the map in Figure 1 of the Eychaner report (Eychaner, 1977). Elevation values were assigned by selecting cells in the model that lay along the contours and assigning constant elevation values to them. The elevations for cells between the contours on the map were interpolated from the cells lying along the map contours and entered cell by cell.

Bottom Elevations

Some data showing the thickness of the valley fill was available from borehole logs in the Figure 1 of the Sunrise Engineering report (Sunrise, 1999). However, the scope of this data was limited to the middle section of the valley. Some approximate thicknesses for the valley fill in the northwestern end of the valley were given in the Sumsion report (Sumsion, 1971). The thickness of the valley fill in the southeast end of

the valley was inferred from the trend of the known data points. The valley fill seems to get thinner going from the northwest to the southeast.

Scatterpoints with these thicknesses were created and the values interpolated to a grid matching the model grid. However, there was insufficient data in some areas of the model to achieve an acceptable interpolation. Estimates of thicknesses for the areas of Layer 1 with no data available were taken from the transmissivity values used by Eychaner in his model (Eychaner, 1977). Bottom elevations for Layer 1 were then assigned by subtracting the layer thickness values from the top elevations.

Layer 2

Top elevations

The top elevations for Layer 2 were assumed by GMS to be the same as the bottom elevations of Layer 1.

Bottom elevations

There are several borehole logs in the Sunrise Engineering report that penetrate more than 400 feet deep. They indicate that the sandstone is permeable enough to yield water to wells at that depth. A constant thickness of 400 feet was assumed for Layer 2, since there are no data available showing exactly how deep the fractured and highly permeable rock in the Glen Canyon Group extends. The thickness was subtracted from the bottom elevations of Layer 1 to obtain the bottom elevations for Layer 2.

A result of the assumption of constant thickness was that high spots in the land surface also produced high spots in the bottom elevations. In the model, this caused the areas with high bottom elevations to artificially dry out when the water table dropped below the bottom elevations of the cells. This problem was especially pronounced at the

edges of the valley where the valley walls rise steeply above the valley floor. For these situations, the bottom elevations were adjusted manually to smooth out the high spots and abrupt changes in elevation.

Boundary Conditions

Colorado River

The northwestern boundary of the model is the Colorado River. A constant head boundary condition simulates the long-term average water level of the river across this boundary. The head level along the boundary varies from 3950 feet near The Portal to 3952.5 feet at the upstream end of the boundary condition, near the location where U.S. Highway 191 crosses the river (Eychaner, 1977).

No-Flow

The western boundary of the model follows the western valley wall. Since there is very little water discharging from springs (in contrast to the amount of water discharged from springs on the eastern side of the valley) this boundary is considered to be a no-flow boundary (Eychaner, 1971).

Constant flux

It was not possible to extend the eastern and southern boundaries of the model out to a groundwater divide or other no-flow boundary condition. There were insufficient data to describe the model parameters outside of the Spanish Valley area. Eychaner used a constant flux boundary condition in his model to simulate the recharge entering the eastern side of the valley. We implemented a similar boundary condition using the same distribution of flux rates along the boundary as did Eychaner (Eychaner, 1977), but scaled

the flux rates down slightly so that the total flux entering the model from this boundary was 13,300 ac*ft/yr. This is consistent with the recharge estimated by Sumsion in his water budget (Sumsion, 1971). The location and extent of the constant flux boundary condition are marked by the Xs in Figure 3.

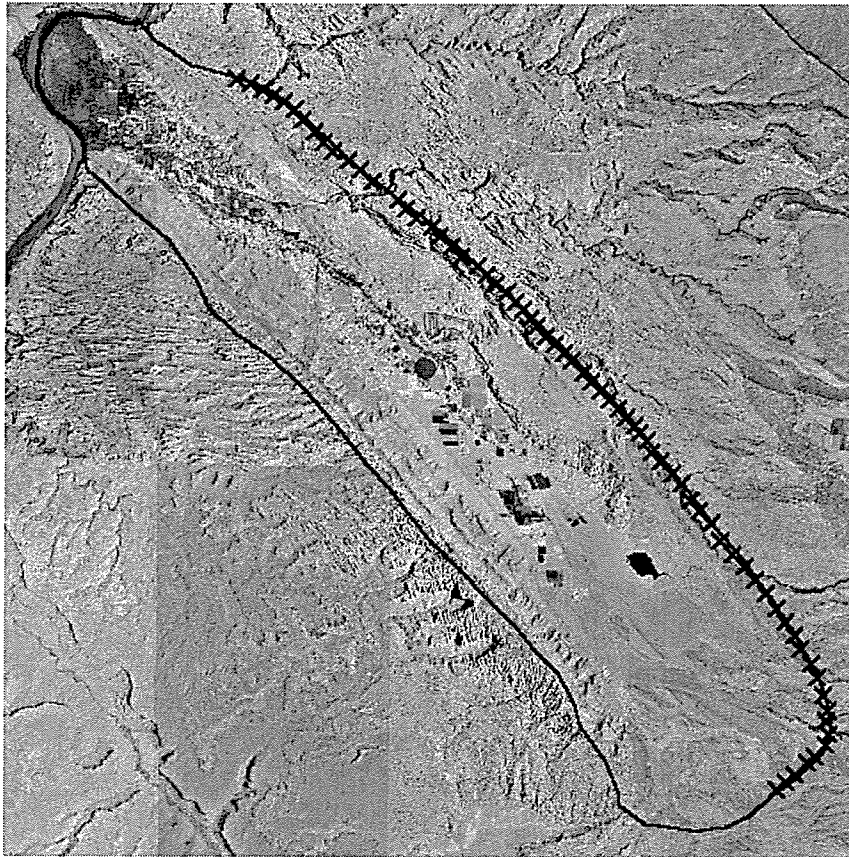


Figure 3: The constant flux boundary condition on the eastern side of the model

Ken's Lake

Ken's Lake was modeled using a general head boundary condition. Water level data were not available, so a long-term average for the water level in the lake could not be determined. During model calibration, the water surface elevation and conductance of the lake bed deposits were adjusted to produce a flow rate out of the lake as close to 3,300 ac*ft/yr as possible.

Recharge

The recharge zones used in the model are shown in Figure 4. As has been mentioned previously, the small zones along the eastern side of the model represent areas where recharge is enhanced by eolian deposits that protect infiltrating water from evapotranspiration while it seeps into the fractured-rock aquifer (Steiger and Susong, 1997). In general, the recharge values assigned to the rest of the zones ranged from 0.0625 inches in the northwest end of the model to 0.5 inches in the southeast. Lower values were assigned to zones in the northwest where precipitation is lower and the soils are less permeable. A zone covering most of the city of Moab was given the lowest recharge value since much of the area is paved. Higher values were assigned to zones in the southeast where there is more precipitation and the soils are more permeable. The area-weighted average recharge over the entire model is 0.25 in/yr.

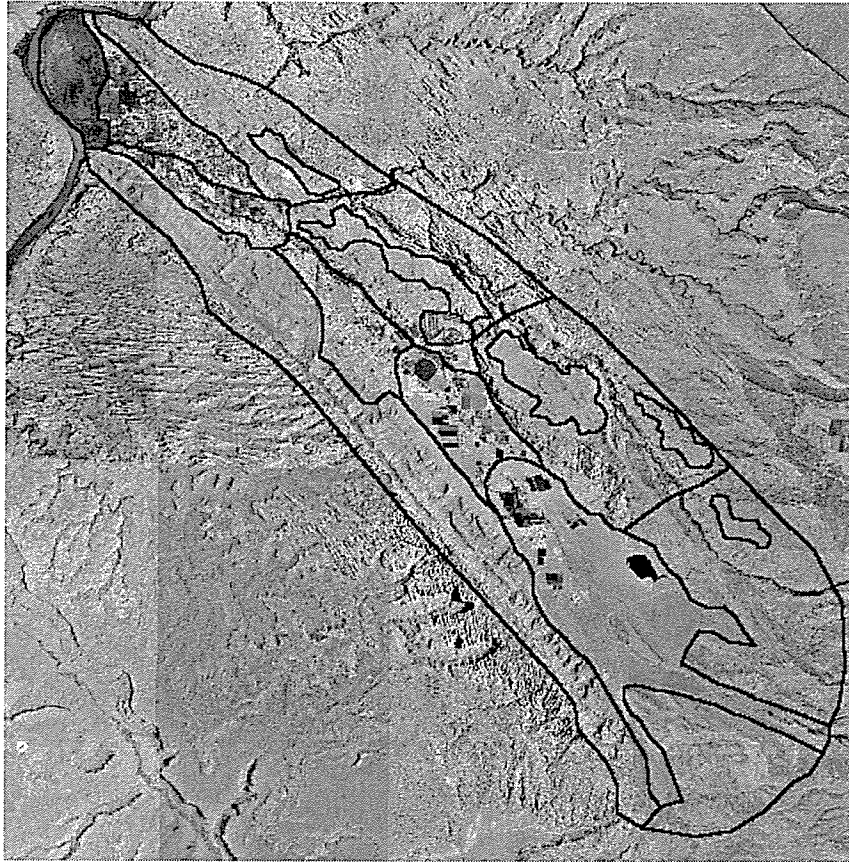


Figure 4: Recharge zones

Sources/Sinks

City Wells

The wells that feed Moab's water distribution system are located in the Moab golf course, and all are completed in the Glen Canyon aquifer. A long-term average of water usage was computed to be 3,335,674 gal/day (Moab, 1999). This is a conservative average, since it is computed using water usage totals from 1996 and 1997, the years with the highest water usage recorded in recent years. This average water usage is equivalent to 445,946 ft³/day, which was distributed over the wells in the city well field in this manner:

| | | | | |
|----------|---|------------------------------|---|---------------|
| Well #4 | - | 81,820 ft ³ /day | = | 425 gal/min |
| Well #5 | - | 81,820 ft ³ /day | = | 425 gal/min |
| Well #6 | - | 118,670 ft ³ /day | = | 616.4 gal/min |
| Well #7 | - | 81,820 ft ³ /day | = | 425 gal/min |
| Well #10 | - | 81,820 ft ³ /day | = | 425 gal/min |

This distribution is consistent with what has been observed in pumping records. Well #6 is generally pumped at a higher rate than the others, while wells #4, 5, 7 and 10 are pumped at close to the same rate (Blanchard, 1990).

Several of the springs located in the Moab golf course are connected to the Moab municipal water system. In order to keep the amount of water withdrawn from the aquifer consistent with the city of Moab's municipal water usage stated above, the water from the springs was added to the amount that was pumped from the city wells.

County Wells

Information from the Grand County Water and Sewer Service Agency (Pierson, 2000) indicates the following pumping rates for the wells that it operates:

| | | | | |
|----------------------|---|------------------------------|---|--------------|
| George White Well #4 | - | 125,100 ft ³ /day | = | 650 gal/min |
| George White Well #5 | - | 192,500 ft ³ /day | = | 1000 gal/min |

These wells are located along the eastern valley wall, southeast of the golf course and west of Johnson's Up-On-Top.

There are various agricultural and private wells that were not included in the model due to lack of current pumping rate data. Old pumping records show that they are all pumped at very low rates compared to the wells shown above, so any effects from these wells were neglected.

Mill Creek and Pack Creek

Both Mill Creek and Pack Creek are gaining streams throughout most of the Spanish Valley area (Sumsion, 1971). For this reason, they were represented in this model as drains. Water discharging from the groundwater into the creeks is permanently removed from the aquifer and the total amount discharged into the streams is reported in the model output.

Values of conductance per unit length for the drain cells were estimated by multiplying the hydraulic conductivity in the area by an average estimated 4-foot width of the channel. A unit thickness for the creek bed sediments was assumed. GMS then computed the conductance value for each cell by computing the length of creek in each cell and multiplying that by the assigned conductance per unit length. Bottom elevations for the creek beds were computed by subtracting between 3 and 5 feet from the cell top elevations in the valley fill and between 10 and 20 feet where Mill Creek flows in a steep-walled canyon as it enters the valley.

Hydraulic Conductivity Zones

Layer 1

Data from the Sumsion and Sunrise Engineering reports indicate that the soils with the lowest hydraulic conductivity occur at the northwest end of the valley, especially in the wetland area near the Colorado River. Soils with higher hydraulic conductivities occur in the middle of the valley (Sumsion, 1971; Sunrise, 1999). There were no data available indicating hydraulic conductivity values for the southeastern end of the valley. However, that area is known to be a high recharge zone composed of coarse-grained soils

(Steiger and Susong, 1997), which is consistent with the probable deposition mechanism stated earlier. For this reason, it was assumed that hydraulic conductivity values for the southeastern end of the valley would be higher than those in the middle of the valley. The horizontal hydraulic conductivity values used in this model ranged from 40 ft/day in the wetland to 250 ft/day in the southeastern end of the valley. The vertical hydraulic conductivity values were assumed to be about one-fourth of the horizontal conductivity values, due to soil layering effects. The hydraulic conductivity zones in Layer 1 are shown in Figure 5.

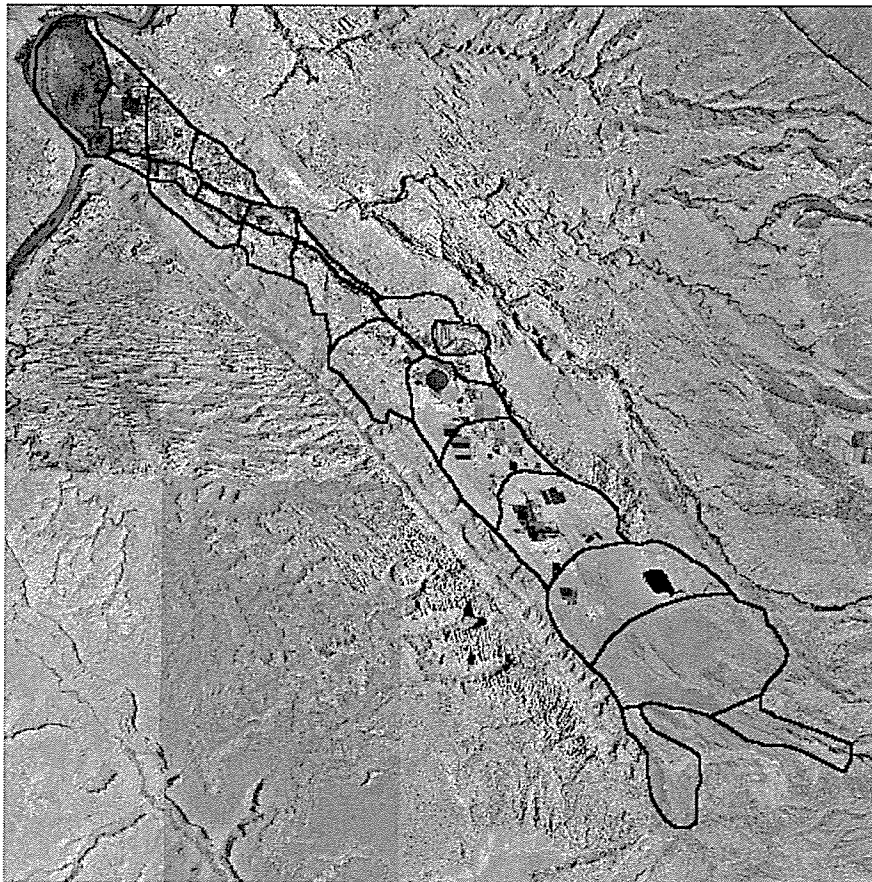


Figure 5: Hydraulic conductivity zones for Layer 1

Layer 2

The Glen Canyon Group sandstones that make up the Glen Canyon aquifer are highly fractured along the eastern side of Spanish Valley and readily yield water to wells. The Moab city well field and the wells operated by the Grand County Water and Sewer Service Agency are located in this area of fractured rock. Results from an aquifer test performed by Blanchard indicate that the Glen Canyon Group is structurally complex and that aquifer characteristics vary considerably in short distances (Blanchard, 1990). Other aquifer tests show that hydraulic conductivity values in the Glen Canyon Group vary from 0.0037 ft/day in unfractured areas to 88 ft/day in highly fractured areas (Eisinger and Lowe, 1999). Zones of average hydraulic conductivity following the fracture lines in the aerial photograph were used in this model to simulate the effects of the high permeability areas in the rock.

The floor of Spanish Valley is probably faulted as well, although to a lesser degree than the highly fractured zone on the eastern side of the valley (Sumsion, 1971). Groundwater flow will occur primarily through preferential flow channels in these fractures, causing the average hydraulic conductivity of the rock beneath the valley floor to be greater than the unfractured hydraulic conductivity.

The horizontal hydraulic conductivity values used in this model ranged from 1.0 ft/day along the valley floor to 30 ft/day in the highly fractured zone. The layering phenomena that affect vertical groundwater flow in soil were not expected to affect flow in fractured rock. Therefore, the vertical conductivity values in Layer 2 were assumed to be the same as the horizontal conductivity values. The hydraulic conductivity zones in Layer 2 are shown in Figure 6.

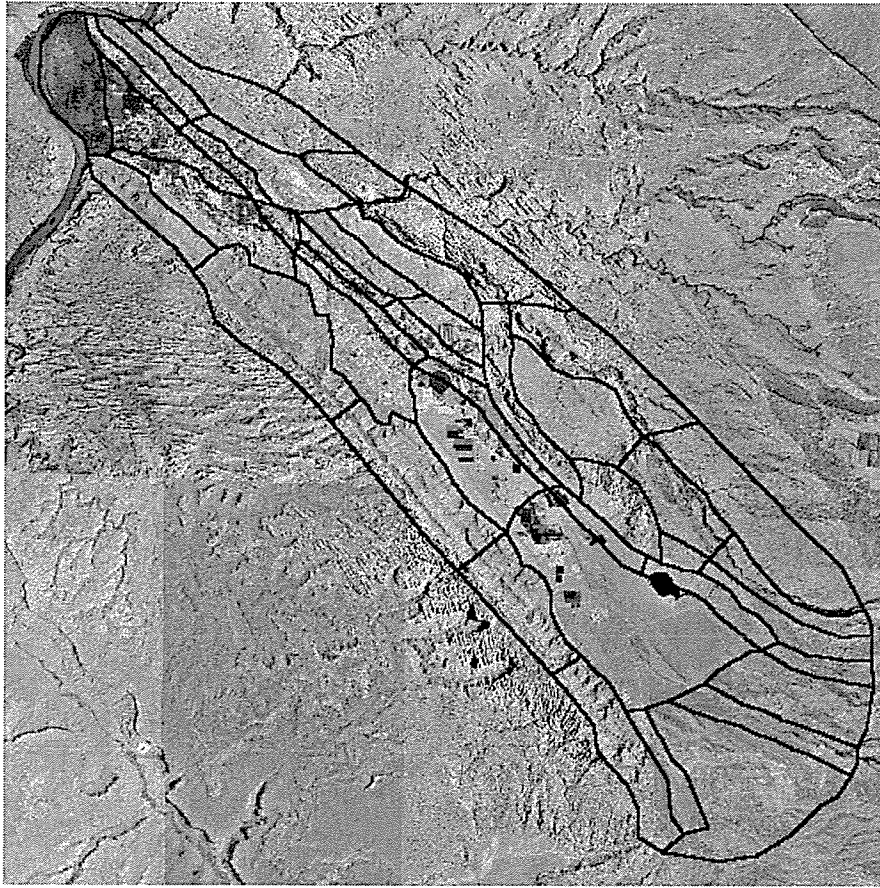


Figure 6: Hydraulic conductivity zones for Layer 2

Model Calibration

The groundwater levels in the model were calibrated to water level measurements in 14 wells contained in the Sunrise Engineering report (Sunrise, 1999). A table of the measured water levels used in the calibration is given in Appendix A. Several flux rates from the water budget in the published reports were also used to calibrate the model.

RMS Error

The best root-mean-squared (RMS) error that could be achieved in the calibration was 60 feet. This is a reasonable amount of error for several reasons. (1) An important aspect of the groundwater flow system in Spanish Valley is flow through fractured rock. As was mentioned above, the Glen Canyon Group is structurally complex and aquifer

characteristics vary considerably in short distances (Blanchard, 1990). The exact locations of the fractures are not known and had to be approximated with zones of average hydraulic conductivity. The zones were inferred from the fractures visible in the arial photograph and from the fault line traced in Figure 1 of the Sunrise Engineering report (Sunrise, 1998). Zones of higher hydraulic conductivity were placed along the fault and where the surface appeared to be more fractured. These zones may not completely describe the flow system. (2) The water level measurements used in the calibration were instantaneous measurements, not long-term averages of the water elevation. Since they were taken over a span of about 7 years, some fluctuation in the water levels is possible. (3) The only hydraulic conductivity values available for the Glen Canyon Group sandstones were the ranges referred to earlier. No site-specific values were available for use in estimating the values that should be assigned to each zone. (4) The only hydraulic conductivity values available for the valley fill were in the northwest and middle sections of the valley. Hydraulic conductivity values for the southeast section of the valley had to be estimated from the trend of the known values. (5) The RMS error value is sensitive to any large point error values. There is one observation point with an error of 172 feet. Without this point, the overall RMS error drops to 41 feet.

Water Budget

In addition to the water level measurements, the following flux rates were used in the calibration:

Groundwater discharge to Matheson Wetland and Colorado River = 11,000 ac*ft/yr
(Sumsion, 1971)
Groundwater discharge to Mill and Pack Creeks = 8,800 ac*ft/yr
(Sumsion, 1971)
Leakage from Ken's Lake to groundwater = 3,300 ac*ft/yr
(Pierson, 2000)

The water budget results for the model calibrated to existing groundwater conditions are as follows:

| | <u>ac*ft/yr</u> |
|--|-----------------|
| <u>Inflow</u> | |
| Recharge from eastern boundary | 13,300 |
| Recharge from precipitation | 730 |
| Leakage from Ken's Lake | <u>7,880</u> |
| Total | 21,910 |
| <u>Outflow</u> | |
| Groundwater discharge to the Colorado River and evapotranspiration in wetland | 4,910 |
| Discharge to Mill and Pack Creeks | 10,590 |
| Consumptive use | <u>6,400</u> |
| Total | 21,900 |

The flux rates for Recharge and Consumptive use could be controlled directly, so they match the amounts given in the literature. The flux rates for the other items were controlled indirectly by adjusting conductance and elevation parameters for the various boundary conditions during the model calibration process. Leakage from Ken's Lake could not be reduced any farther without causing model instability. However, the amount of the water entering the model through Ken's Lake in excess of 3,300 ac*ft/yr is partially cancelled out by the amount of water discharging to Mill and Pack Creeks in excess of 8,800 ac*ft/yr. Also, as has been stated previously, it is not known how much of the 8,800 ac*ft/yr in the literature is attributed to groundwater and how much is attributed to

surface runoff. If the actual amount of groundwater discharged to Mill and Pack Creeks is less than 8,800 ac*ft/yr, it may be that the excess inflow from Ken's Lake is almost fully cancelled out by the excess discharge to Mill and Pack Creeks.

Results

Model of Existing Conditions

Contours of water table elevation in Spanish Valley computed by the model are shown in Figure 7. The contours indicate flow toward the northwest, meeting the Colorado River at an elevation of 3950 feet. The contours shown in Figure 7 are for Layer 2, which covers the entire modeled area. The water table drops below Layer 1 just to the northwest of Ken's Lake, near the 4800-foot contour.

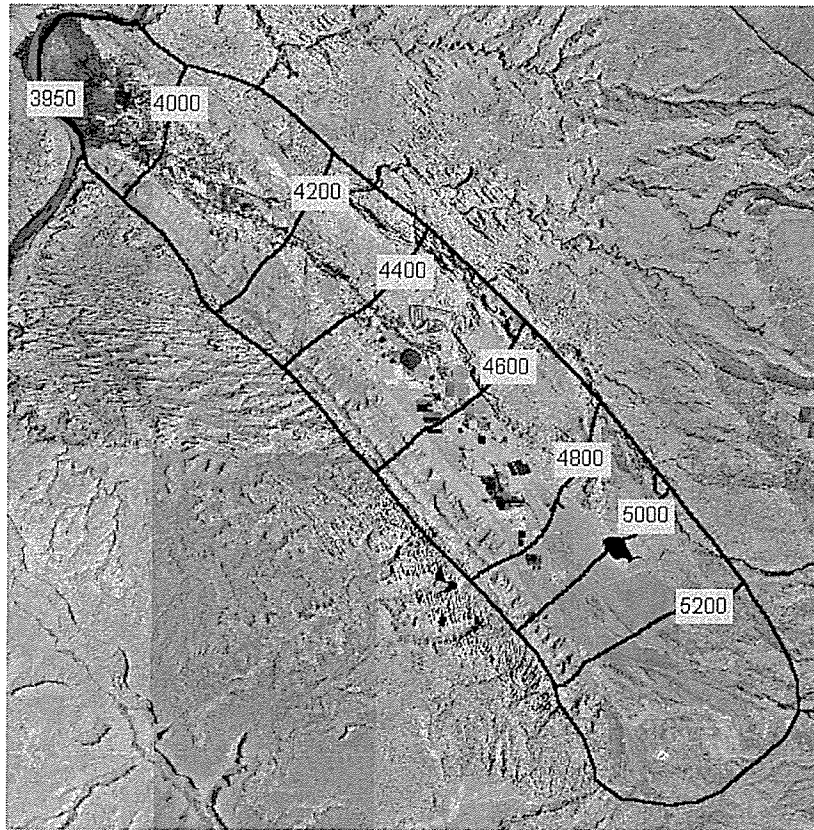


Figure 7: Water table contours under existing conditions

Predictive Simulations

After the model was calibrated to existing conditions, simulations to predict the results of additional stresses to the system were run. Two different conditions were simulated. (1) An additional 1000 gpm was pumped from the Glen Canyon aquifer using two wells located in the highly fractured area along the eastern wall of the valley, northwest of Ken's Lake (see Figure 8). (2) An additional 2625 gpm (4,234 ac*ft/yr) was pumped from four wells in the general area of these sited wells (see Figure 9). Two of the wells are in the same locations as in (1) and the other two are hypothetical wells that distribute the stress to the system so that the wells are not pumped dry.

Comparison of the water table contours in Figures 8 and 9 indicates an expected drawdown of the water table when the larger amount of water is pumped from the new

wells. Clear cones of depression do not form around the wells due to the use of average hydraulic conductivity zones discussed earlier.

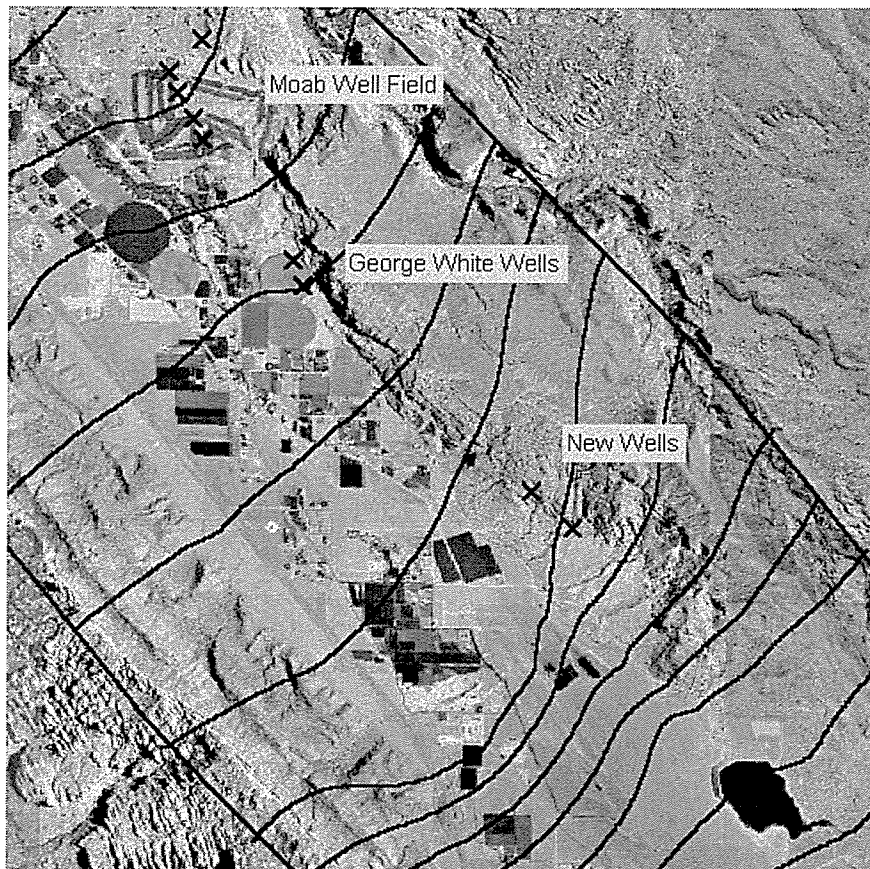


Figure 8: Water table contours with two new wells pumping a total of 1000 gpm

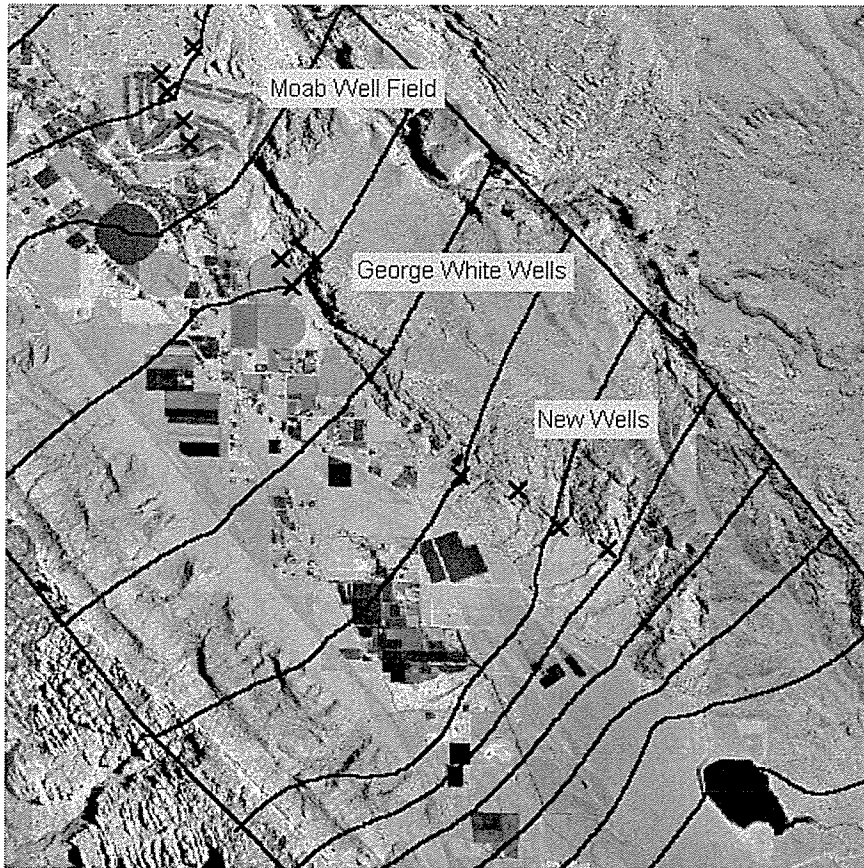


Figure 9: Water table contours with four new wells pumping a total of 2625 gpm

Particle Tracking

Forward and backward particle tracking analyses were performed to help determine the source of the water that is pumped from the wells in Spanish Valley, including the proposed new wells. First, a simulation was run tracking particles backward from the existing wells in the valley while the new wells pumped at a rate of 2625 gpm. The flow paths of the particles show that all of the water that supplies the existing wells comes from the eastern side of the valley (see Figure 10).

A second simulation was then run tracking particles forward from Ken's Lake. About half of the particles were taken into the new wells, while the remainder passed by on the western side of all of the wells and traveled to the end of the valley, eventually

exiting the model into the Colorado River (see Figure 11). This indicates that Ken's Lake would supply water to the new wells and that lower quality water from the western side of the valley would not be drawn to the wells on the eastern side.

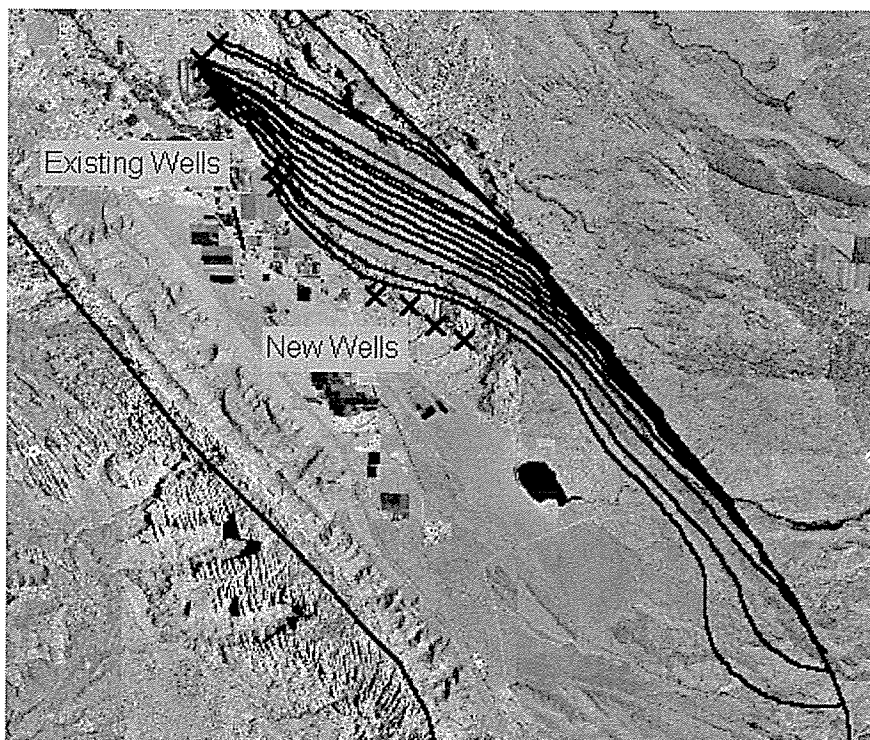


Figure 10: Particle flow paths traced backward from the Moab city well field and George White wells when the new wells are pumping 2625 gpm

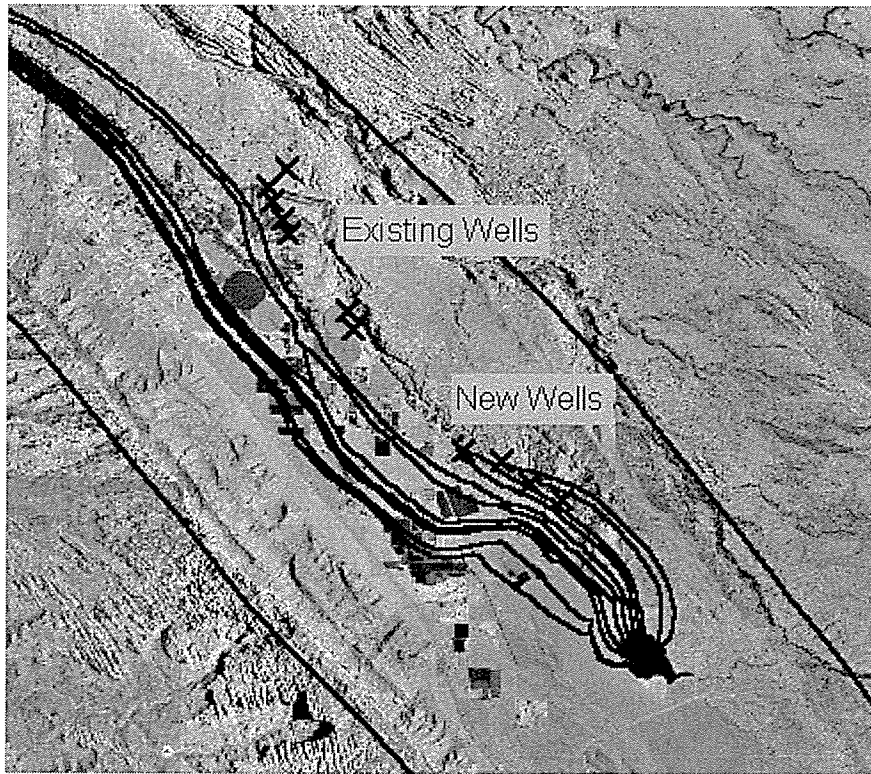


Figure 11: Particle flow paths traced forward from Ken's Lake

Wetland

During the process of building this model, an additional consideration for quantifying the amount of water that could be withdrawn from the aquifer was discovered. The Scott M. Matheson Wetland Preserve at the northwest end of the valley is fed by water from the valley fill aquifer. Environmental regulations require that the wetland not be adversely impacted by the withdrawal of more water from the aquifer.

The model predicts that less than an inch of drawdown will occur when the full 4,234 ac*ft/yr is withdrawn. The wetland covers approximately 8 acres, so a loss of 1 inch of water over the entire wetland amounts to a reduction of 0.67 ac*ft/yr from the water feeding the wetland.

Conclusions

This model shows that the Grand County Water and Sewer Service Agency can withdraw an additional 4,234 ac*ft of water per year from the groundwater in Spanish Valley and that withdrawing the additional water will not adversely affect the water quality in the valley. Particle-tracking analyses show that the water withdrawn from the wells along the eastern side of the valley is supplied by the Glen Canyon Group or by leakage from of Ken's Lake. When the additional amount of water is withdrawn, lower quality water from the western side of the valley is not drawn into the capture zones of wells on the eastern side. The model also predicts that less than an inch of drawdown will be seen in the wetland.

It appears that the leakage from Ken's Lake has made it possible for the additional water to be withdrawn without affecting water quality in the valley or the wetland. The model shows that nearly half of the water leaking from Ken's Lake will go to supplying the water withdrawn by the new wells.

The complex nature of groundwater flow in Spanish Valley has been approximated in this model. More detailed hydrogeologic data about Spanish Valley, especially the eastern side of the valley, will have to be gathered in order to obtain more accurate results from this type of a groundwater model. In particular, more specific hydraulic conductivity or transmissivity data for the fractured-rock area on the eastern side of the valley and more detailed delineation (both lateral and vertical extent) of the zone of highly fractured rock are needed.

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Appendix A

| Sunrise Report Well # | Surface Elevation (ft) | Bottom Elevation of Valley Fill (ft) | Water Table Elevation (ft) | Bottom Elevation of Well in Rock (ft) |
|--------------------------|---------------------------|---|-------------------------------|--|
| 4 | 4875 | 4700 | 4719 | 4600 |
| 16 | 4727 | 4532 | 4593 | 4432 |
| 17 | 4716 | 4446 | 4588 | 4346 |
| 19 | 4742 | 4550 | 4587 | 4450 |
| 20 | 4705 | 4525 | 4587 | 4425 |
| 36 | 4725 | 4485 | 4601 | 4385 |
| 39 | 4728 | 4510 | 4603 | 4410 |
| 50 | 4856 | 4623 | 4652 | 4523 |
| 57 | 4677 | 4457 | 4609 | 4357 |
| 58 | 4706 | 4504 | 4611 | 4404 |
| 59 | 4667 | 4484 | 4595 | 4384 |
| 60 | 4749 | 4504 | 4632 | 4404 |
| 79 | 4645 | 4395 | 4573 | 4295 |
| 80 | 4694 | 4468 | 4590 | 4368 |

Abstract

The Grand County Water and Sewer Service Agency has inquired whether 4,234 ac*ft of additional water per year may be withdrawn from the Spanish Valley Aquifer, and if so, whether its water quality might be affected by more saline water from the western side of the valley. The criteria for determining how much of the water can be withdrawn from groundwater are (1) that the water must be physically available from the aquifer and (2) the quality of the water pumped from other wells in the area can not be adversely affected by drawing lower quality water into their capture zones. Groundwater flow and particle tracking models were developed using GMS, MODFLOW and MODPATH to simulate both the existing and future stressed conditions of the groundwater system. The model results indicate that it is possible to pump the full 4,234 ac*ft/yr from new wells in the valley and that the quality of water pumped from other wells in the area will not be adversely affected.