ALTERNATE CONCEPTUAL MODELS IN THE SATURATED ZONE AT YUCCA MOUNTAIN

Linda L. Lehman
Tim P. Brown

Introduction

The State of Nevada has funded L. Lehman & Associates to conduct research on water level changes in the vicinity of Yucca Mountain. As a result of analyses done over the past several years, L. Lehman & Associates has made several observations. Taken together, these observations can assist in formulating a different and more complex conceptual model of the saturated zone than the models currently being analyzed in performance assessments. These observations lead to a more closely coupled hydro-tectonic concept than previously accepted.

Recently L. Lehman & Associates examined relationships between data collected on spring discharge, monitor well water levels and water levels in Devil's Hole. In studying monitor well water levels, changes were observed apparently coincident with a series of three earthquakes which took place in the southwest. On June 28, 1992 a 7.5 magnitude earthquake occurred near Landers, CA and three hours later a second 6.6 magnitude earthquake occurred near Big Bear, CA. The next day, on June 29, 1992, a 5.6 magnitude quake occurred at Little Skull Mountain, located about 23 km southeast of Yucca Mountain, near the southern boundary of the Nevada Test Site (O'Brien, 1993).

The apparent earthquake effects on well water level varied from well to well. However, the effects can be grouped into four main categories:

- well levels that exhibited an upward temporary spike
- wells that exhibited rapid upward change with an apparent long-term stabilization at a higher level
- wells that showed a downward temporary spike
- and wells that showed rapid downward change with an apparent long-term stabilization at a lower level.

Wells which show increased water levels appear to be associated with SE-NW trending fault zones while those with decreased levels are not closely related to these zones. The difference between the direction of well water level change within and outside the fault zones may indicate hydraulic relationships between these structural zones. It may also give clues about the changes in stress that occur within hydrologic units due to earthquakes.

These observed responses suggest that some areas experience compressive strain, reducing effective pore volume and raising water levels. While other areas are experiencing tensile strain, increasing effective pore volume and lowering water levels. With the progress of site characterization at Yucca Mountain, some important questions about the basic mechanisms affecting flow in the saturated zone below Yucca Mountain have emerged. Some of these questions include:

- What is the role of faults in saturated zone flow?
- How do earthquakes affect saturated zone flow?
- How would changes in insitu stress affect water levels?
- How does geothermal heat flow affect the saturated zone flow dynamics?
- What causes the large head gradient in the water table north of Yucca Mountain?

As more information is collected, it becomes apparent that the saturated zone flow dynamics are influenced by complex interplay between the basin and range tectonics, and the local geologic structure.

This presentation outlines data analyses performed at L. Lehman & Associates which suggests that there exist semi-isolated zones of groundwater flow within a larger structurally controlled system. The analyses also indicate the insufficiency of a simple saturated zone conceptual model for accurately describing the system.

A. Cosine Components

In 1990 L. Lehman & Associates examined water level data from 8 water table wells located around Yucca Mountain (Lehman, et al, 1990). The water level data were fit with a cosine function using the Fit.M program of Rice (1989). This was done to examine possible cyclic behavior in water levels and to use this information in examining relationships between the saturated zone and recharge mechanisms.

Data were analyzed in 1989. The wells referred to here are shown as Figure 1. The work involved looking at similarities in water table oscillations. It was thought that if wells were responding at similar frequencies they may be hydraulically connected. The results of this work indicated similar responses at certain wells located west of Yucca Mountain, and similar responses in wells located to the east of Yucca Mountain. What was interesting about the observation was that the similar behaving wells lined up along a NE-SW direction, a trend parallel with the major fault zones and in perpendicular with the principle tensile stress direction for the region. It also lead to the conclusion that the 2 sides of the mountain were separate hydrologic systems, only loosely connected.

It was found that water levels tended to fluctuate at 2-3 year cycles. Wells west of Yucca Mountain exhibited cycles at the long end of this range of near 1000 days, while those east had fitted periods at the short end of the range at around 880 days. This was the first indication that groundwater flow on either side of Solitario Fault may not be coupled, as is usually assumed in the existing flow models for the area.

B. INTRAVAL Work

Our analyses under the Intraval project lead us to believe that flow in the unsaturated zone could also be controlled by fractures. These analyses lead us to examine the work of Sass

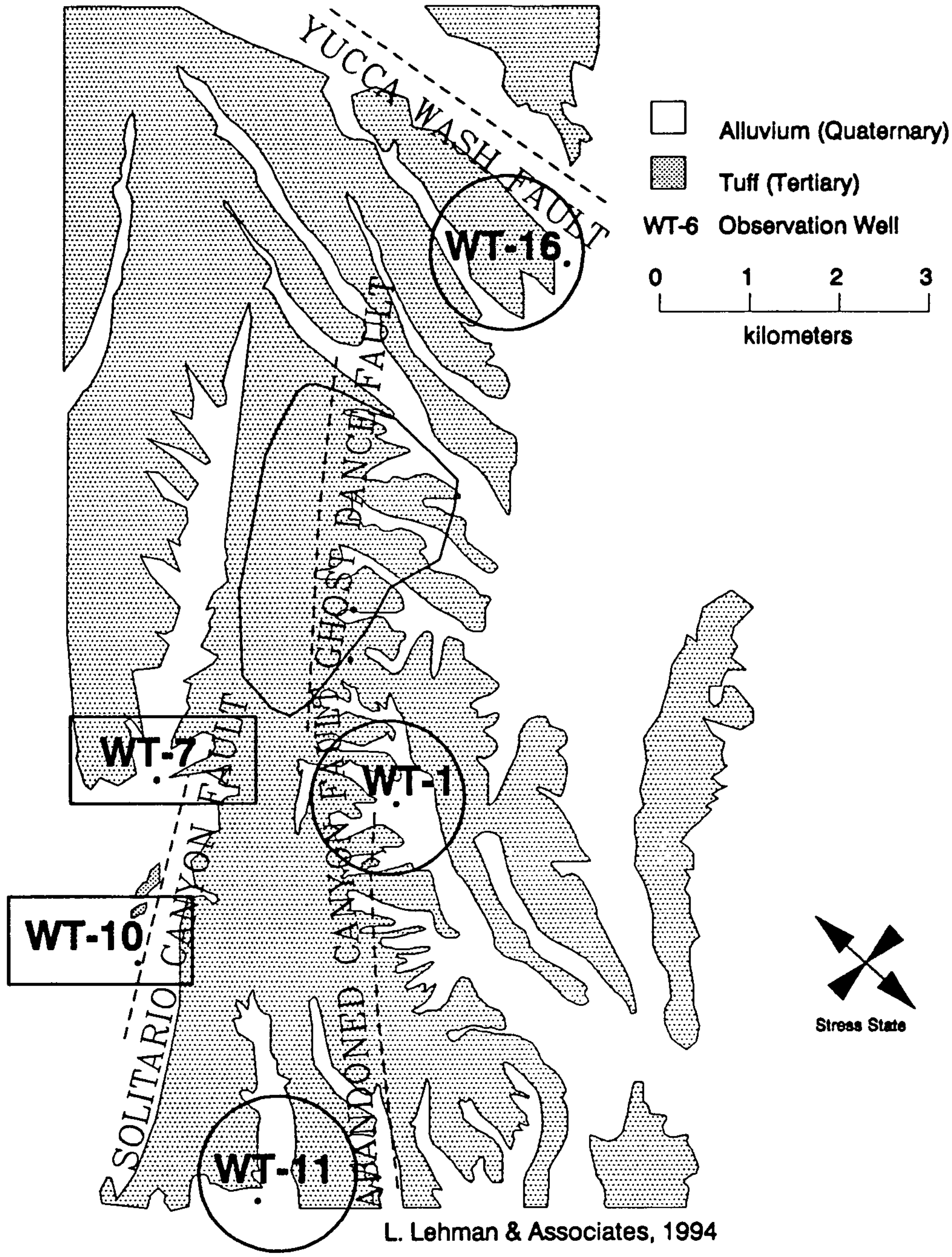

Figure 1. Location of wells that exhibited different fitted periodicity at Yucca Mountain with circles indicating periods of 870 days and squares indicating periods near 1000 days.

et al (1988), which presented temperature measurements with depth at various boreholes including subsurface water temperatures. We noticed, and presented to the Nuclear Waste Technical Review Board last summer, that the water table temperature profiles were coincident with known fracture zones under Yucca Mountain and volcanic centers. This alternative model is shown in Figure 2.

In looking at the distribution of temperature at the water table, it was apparent to Sass and others that saturated zone flow was much more complex than simple 2-dimensional uniform flow. The temperature distributions suggest localized recharge near Ghost Dance Fault and a thermal hot spot along the Solitario Fault zone. This information further complicates interpretation of the effect of local faults on groundwater flow and transport pathways. This information may be indicating that faults serve as pathways for both cool water from the surface as well as warm water upwelling from depths.

C. Devil's Hole

Most recently we examined relationships between water levels in Devil's Hole, and water levels and discharge at other springs and wells in the area. We found that Devil's Hole water levels correlated well with water levels from the AD-7 and AD-8 wells located upstream (Figure 3). But when water levels for a nearby well west of Devil's Hole, AM-7, were examined a negative correlation over time was found. Closer examination showed that most of the negative correlation was due to an opposite response to the earthquakes of June 1992, and that Devil's Hole and well AM-7 were statistically uncorrelated.

The above result was surprising, first because wells 10 miles upstream showed significant correlation with Devil's Hole while the downstream well AM-7, only a mile or so away showed no correlation. Surprising also was the fact that Devil's Hole levels showed a temporary drop, while AM-7 levels rose, in response to the earthquakes. It appeared that Devil's Hole and AM-7 were located on either side of the Stewart Valley Fault which runs through Ash Meadows, and were responding as if they existed in different hydrologic domains.

We then decided to look at all the well data from DOE's Quarterly Groundwater Data Reports from May 1992 through January 1994, which included data from 1990-1993. Specifically, we wanted to examine the direction and magnitude of water level response resulting from the June 1992 earthquakes. The data consisted of well specifications and depth to water measurements taken monthly. This means that we looked at measurements which were taken days to weeks before the quakes and measurements taken in similar time lengths afterward. At this weekly time scale, short term "seismic" effects are not seen, but rather, longer term adjustments in water level. Water level adjustments ranged from negligible to over 15 feet. Only wells with adjustments of magnitude 0.5 feet or more were plotted and their locations compared with fault traces in the area. These wells are shown in Figure 4. Eight wells showed positive change above 0.5 feet and 6 wells had declines greater than 0.5 feet. The well responses are shown in Table 1 and an appendix at the end of this report shows water level plots for these wells.

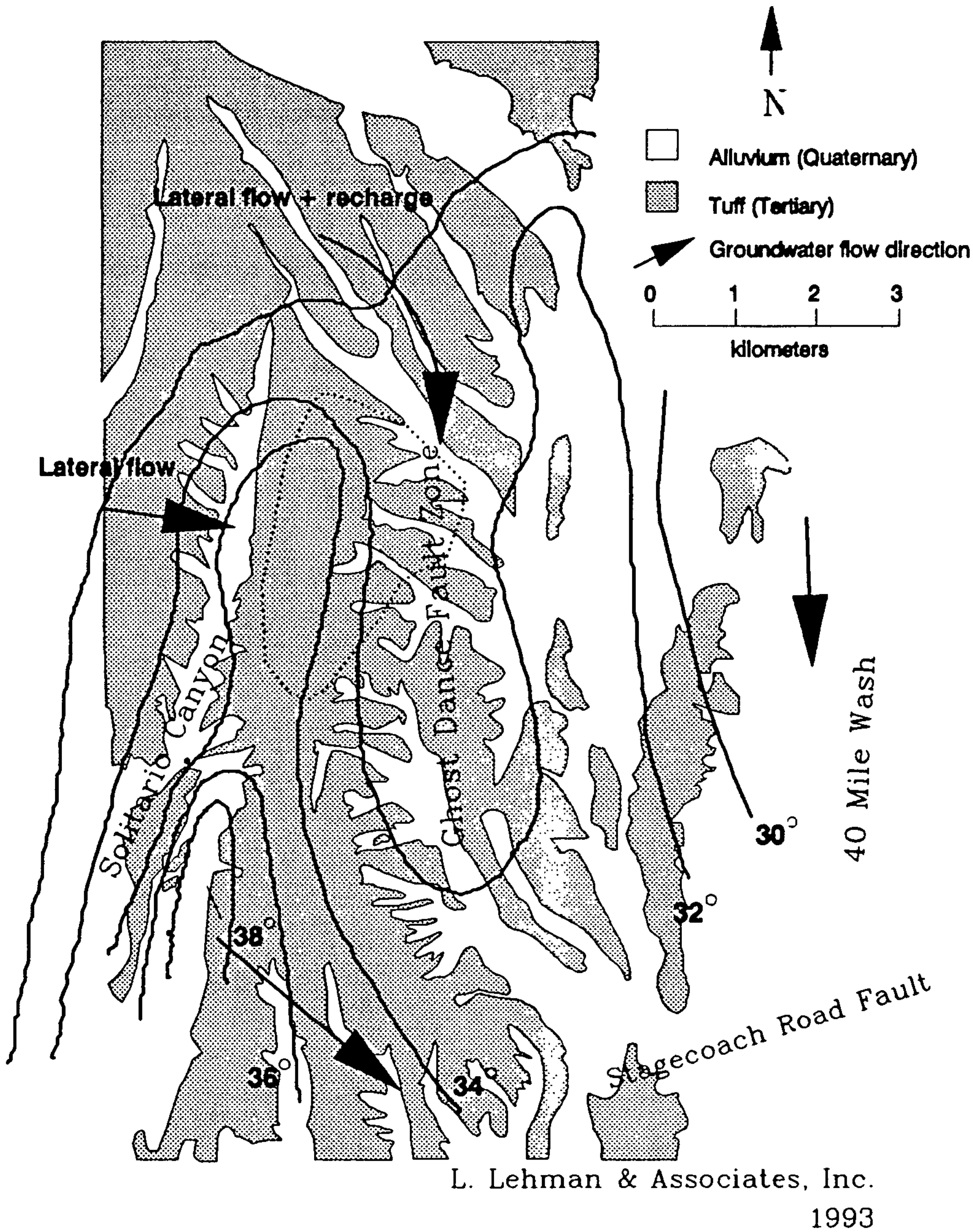

Figure 2. Saturated zone water table isotherms (from Sass et al, 1988).

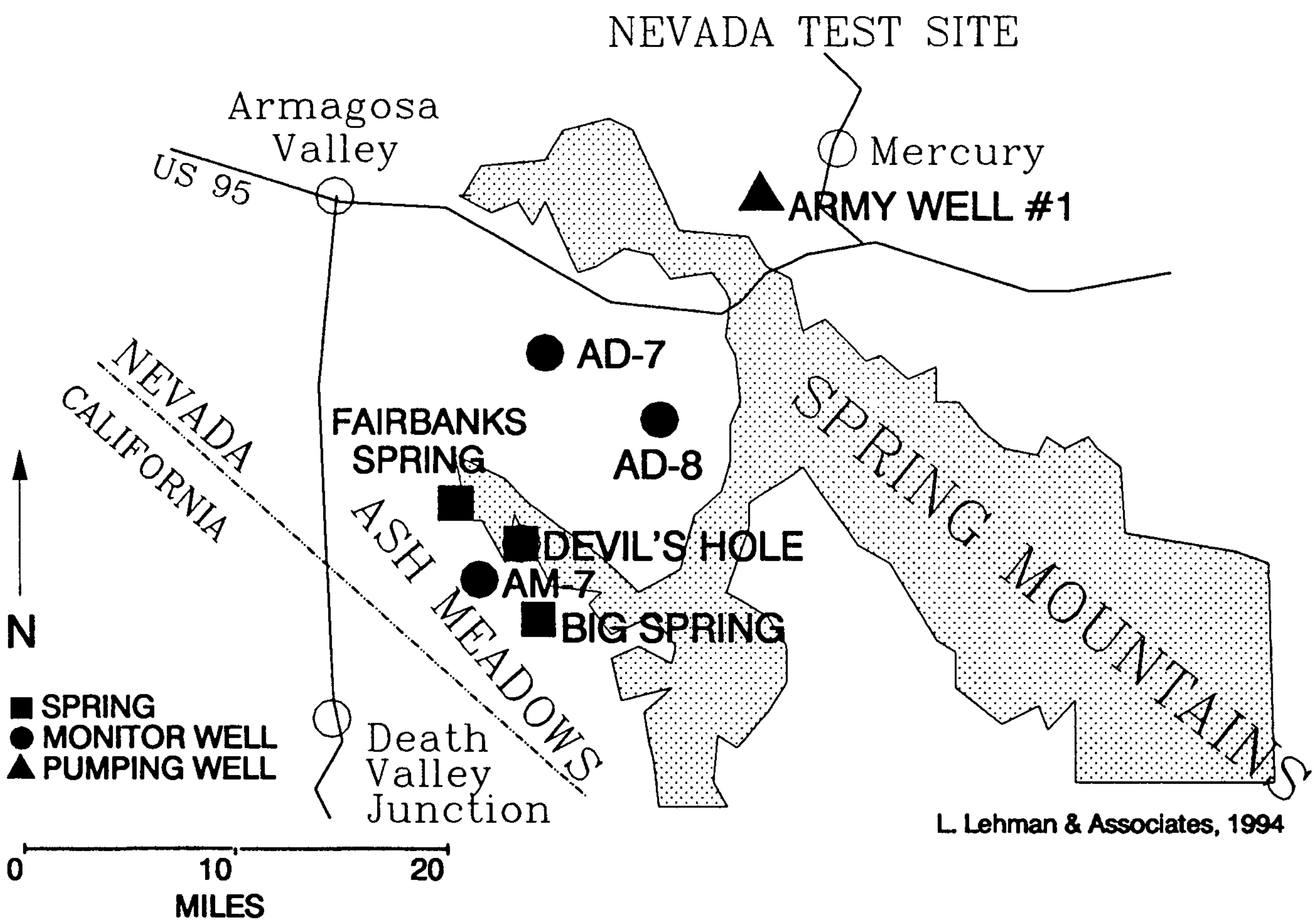

Figure 3. Map showing locations of features examined in Devil's Hole study.

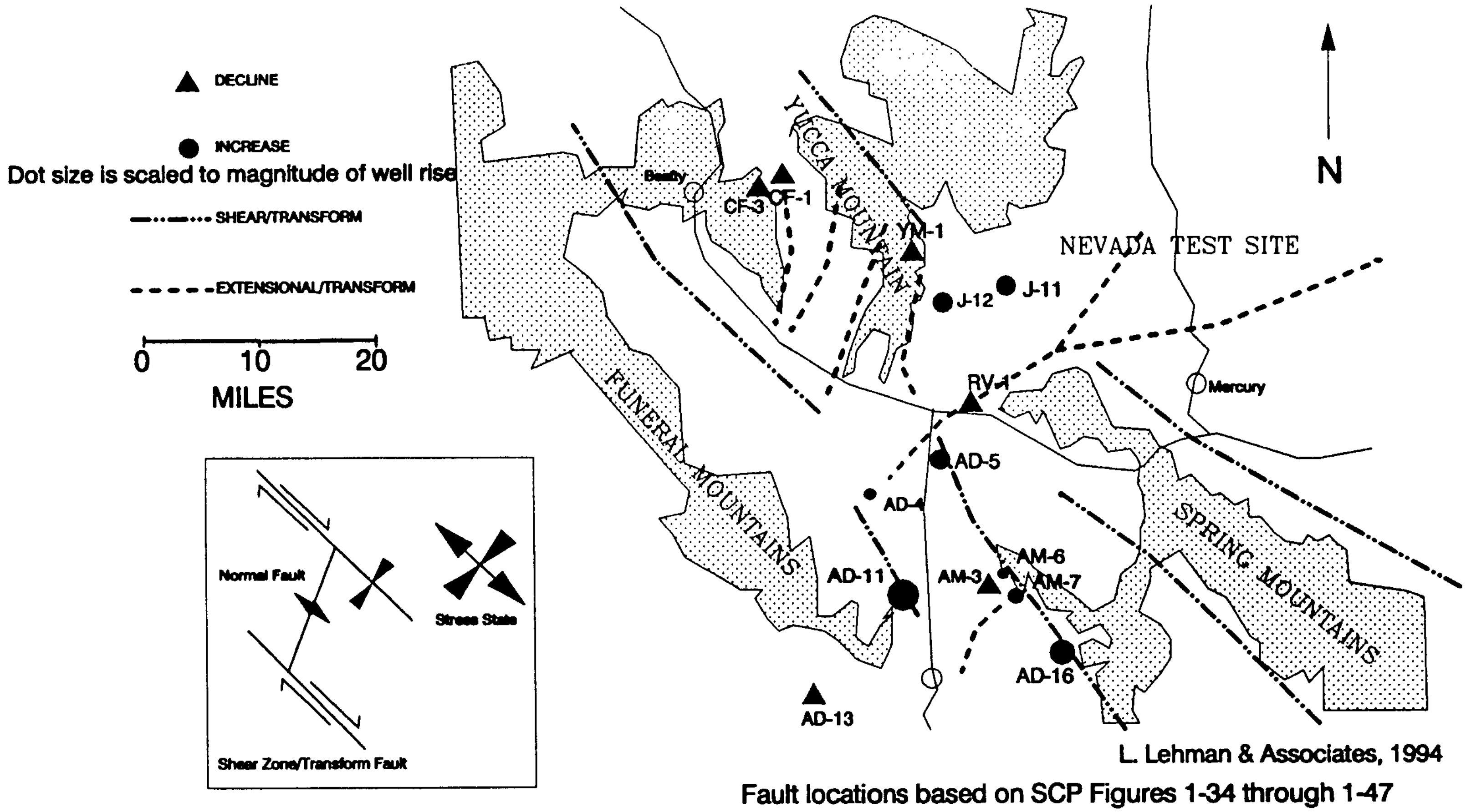

Figure 4. Locations of fault zones and monitored wells that exhibited more than 1/2 feet of sustained water level change between mid-June and mid-July 1992.

Table 1. DOE monitored wells that exhibited more than 0.5 feet of water level change between mid-June and mid-July 1992.

Wells showing decrease			Wells showing increase		
Well ID	Level change (ft)	Geologic Unit	Well ID	Level change (ft)	Geologic Unit
AD-13	-1.8	alluvium	AD-11	15.7	volcanics
CF-1	-1.4	volcanics	AD-16	5.5	alluvium
YM-1	-1.1	carbonates	AD-5	3.5	alluvium
RV-1	-0.7	carbonates	J-12	3.3	volcanics
CF-3	-0.6	alluvium	J-11	3.0	volcanics
AM-3	-0.5	alluvium	AM-7	1.3	carbonates
			AM-6	0.6	carbonates
			AD-4	0.5	alluvium

In examining the relationship between water level changes and fault zones, we found that increases in levels correlated with transform or shear fault zones and decreased levels with extensional or normal faulting. The exact reasons for these changes are unknown but one can speculate on some potential mechanisms:

- Perhaps these responses imply that areas around the transform or shear zones may have experienced a long lasting increase in compression, thereby reducing pore volume, while extensional zones may have experienced long lasting increases in pore volume due to increased tension.

- Alternatively, these long lasting level changes might result from large scale hydraulic adjustment to locally extreme in situ stress changes. Water forced out of zones due to increased compression might "upwell" at some locations where vertical conductivity is high.

- Further, changes in temperature distributions and thermal flow rates brought on by the quakes may also play a role in changing the observed water levels.

The above analyses, rather than providing any clear-cut answers regarding the mechanisms for the observed changes, seriously questions any saturated zone model which does not consider local tectonics, especially the effects of fault zones on flow. Currently these coupled effects are not well understood.

D. Project Implications

These observations may have implications for licensing the Yucca Mountain site. First, this and other work (see Winograd and Thordarson), suggests that the saturated zone flow may be quite complex, with effects from in situ stress and earthquake activity, geothermal heat flow, as well as more obvious structural and hydraulic controls. This means that performance assessment calculations based on simple uniform 2-D flow may be inadequate.

Performance assessments should be done using a wider range of conceptual models which attempt to account for tectonic and thermal affects. They also need to incorporate extreme behavior of the system due to major tectonic events, such as large earthquakes, in order to bound travel times and mass release predictions.

There also needs to be more integration of studies relating to hydrology and tectonics. Scientists from both disciplines will need to work together to answer some of the complex questions that need resolution. For example, it appears earthquake activity will not only affect facility structural integrity, but effect the hydrologic models as well.

The apparent earthquake induced water level changes probably have caused changes in local gradients and flow directions which may increase or decrease travel time calculations. Some fault zones may also be acting as conduits for rapid flow greatly decreasing travel times based on uniform flow assumptions.

The questions raised by these observations call for collection of data on temperature distributions at the water table and with depth, especially within fracture zones. This could shed light on recharge and any upwelling phenomenon that may exist. More data on water levels over time, more densely spaced over specific areas, will also help resolve relationships between faults and flow. Pressure measurements conducted at multiple levels of boreholes would help resolve questions of vertical flow. Therefore, current test plans may have to be revised.

Overall, saturated zone flow is slowly being revealed as much more complex than originally thought. If performance assessment is to be carried out at the necessary level of confidence, it will have to keep pace with the growing level of complexity seen emerging in site characterization data.

References

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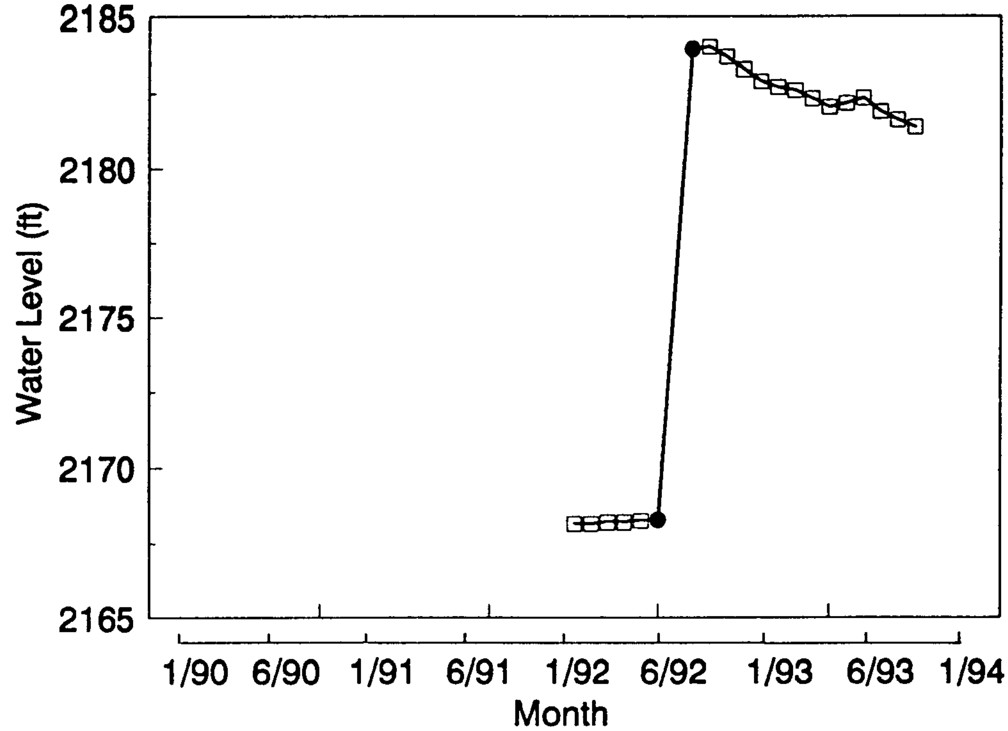
Sass J.H., A.H. Lachenbruch, W.W. Dudley Jr., S.S. Priest, and R.J. Munroe, Temperature, thermal conductivity, and heat flow near Yucca Mountain, Nevada: Some tectonic and hydrologic implications, USGS Open-file Report #87-649, 1988.

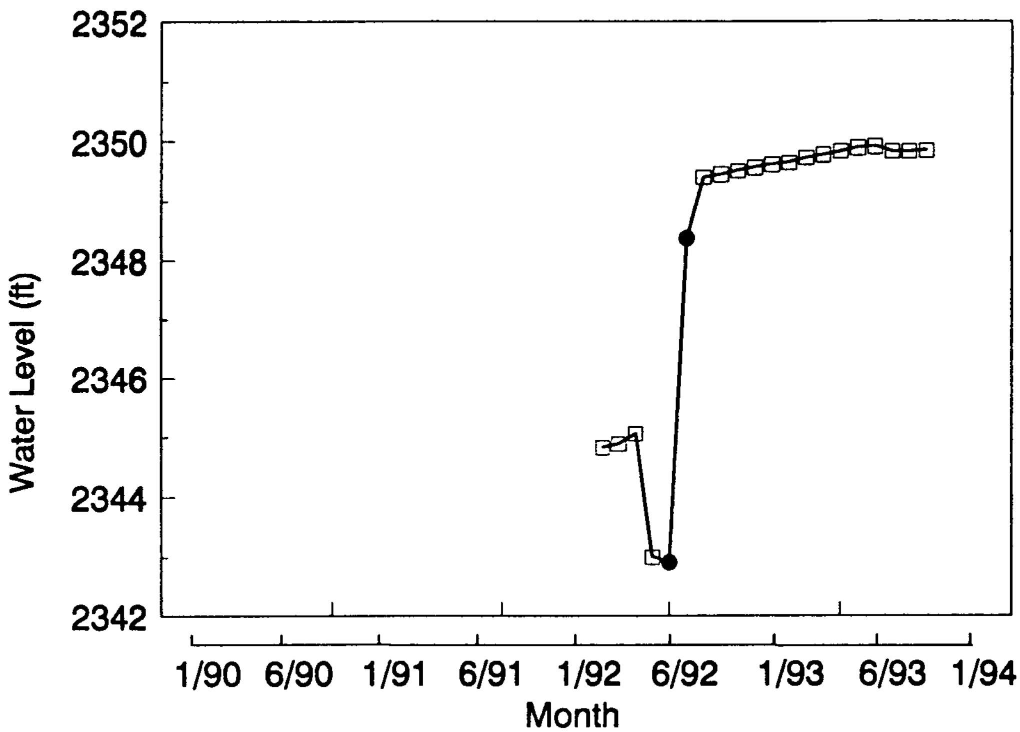
Winograd, I.J., and Thordarson W., Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site, USGS Professional Paper #712-C, 1975.

APPENDIX: Plots of water levels over time for DOE monitor wells with measurements taken immediately before and after the June 1992 earthquakes shown as black circles and other measurements shown as hollow squares.

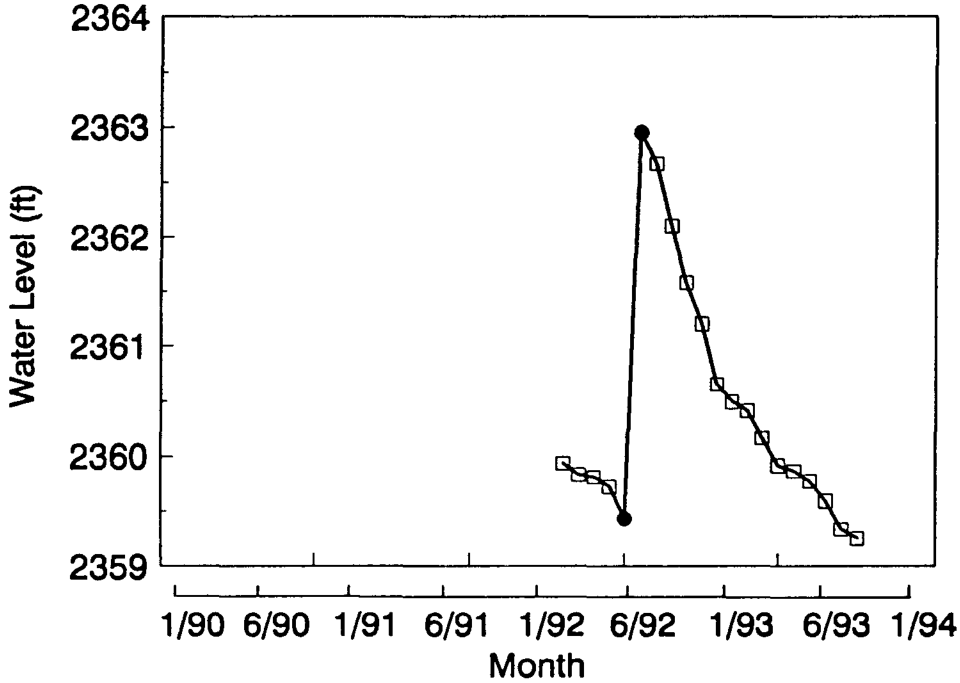
Monthly water level measurements for monitor well AD-11



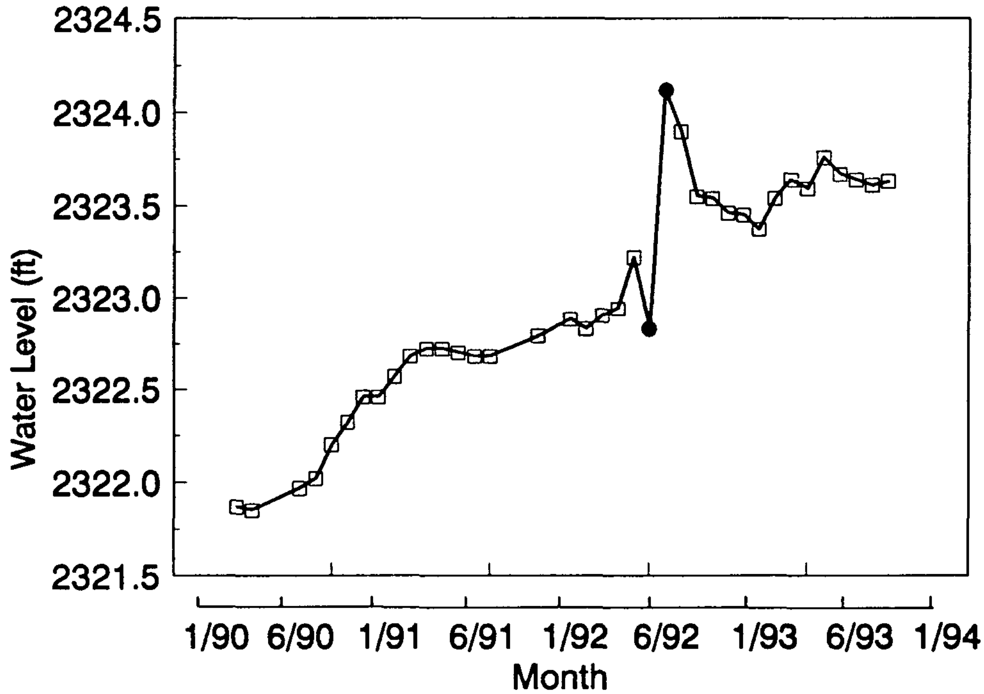
Monthly water level measurements for monitor well AD-16



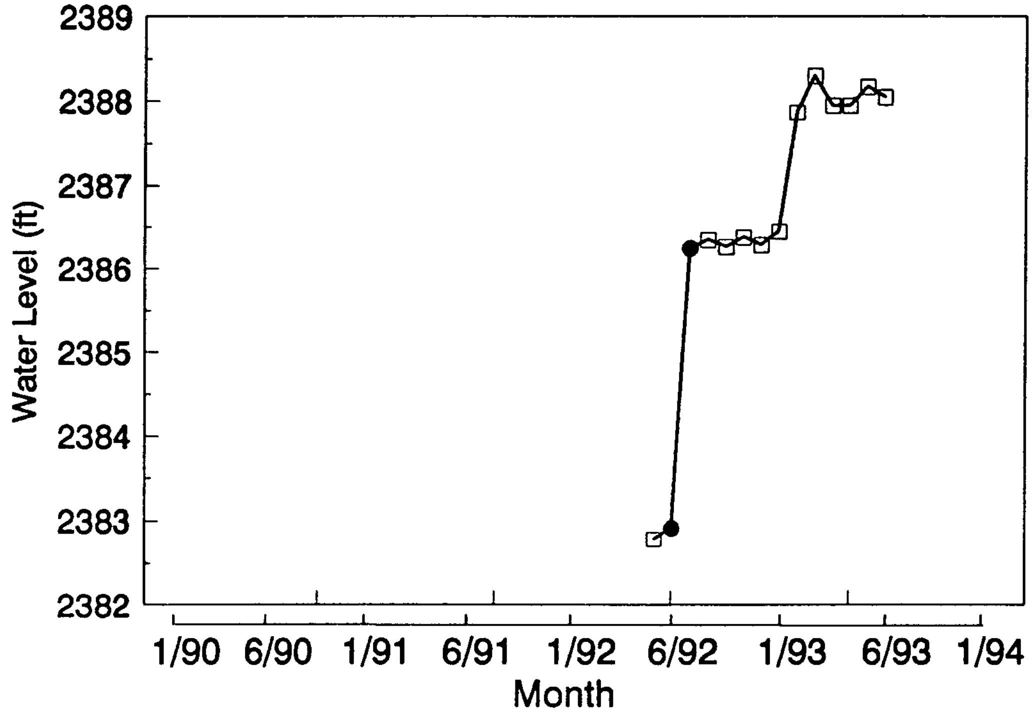
Monthly water level measurements for monitor well AD-5



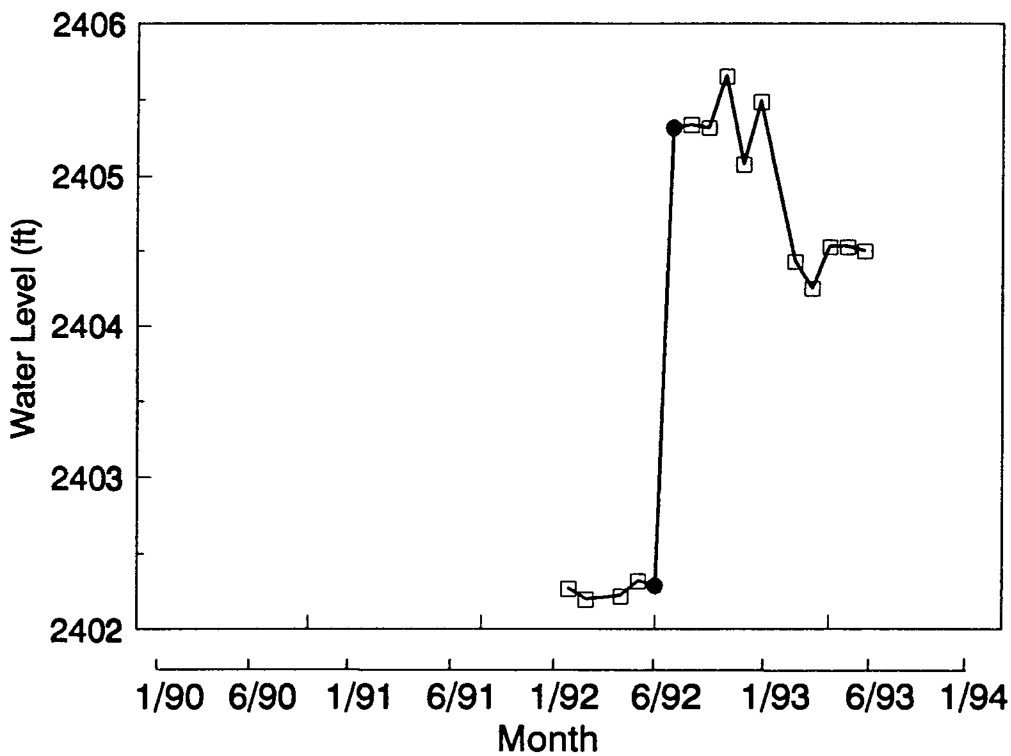
Monthly water level measurements for monitor well AM-7



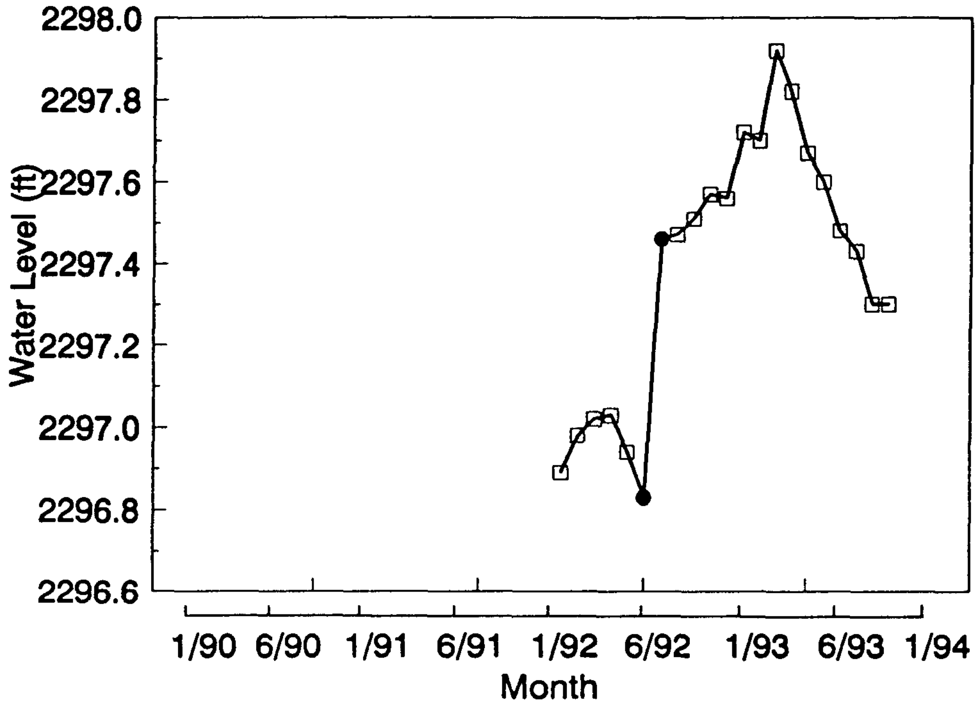
Monthly water level measurements for monitor well J-12



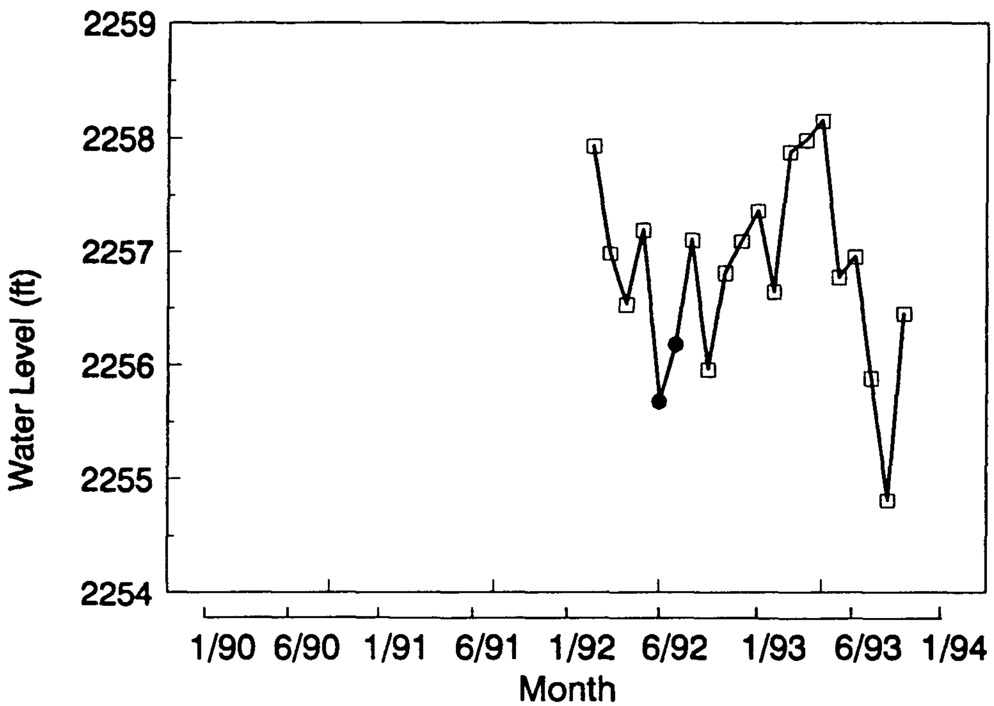
Monthly water level measurements for monitor well J-11



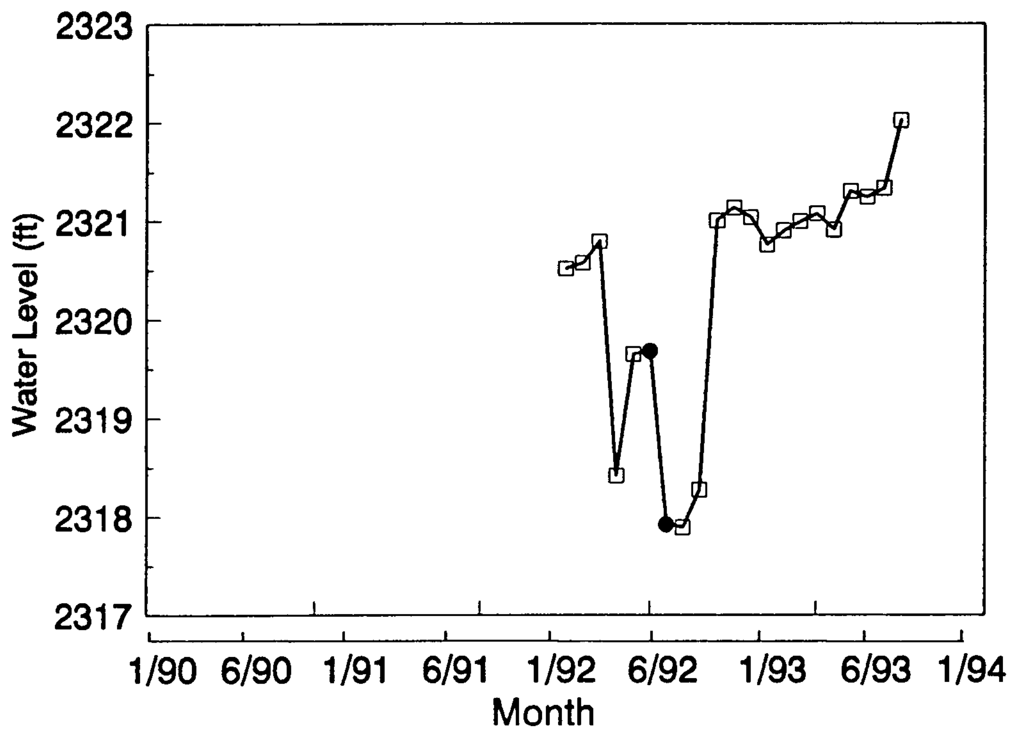
Monthly water level measurements for monitor well AM-6



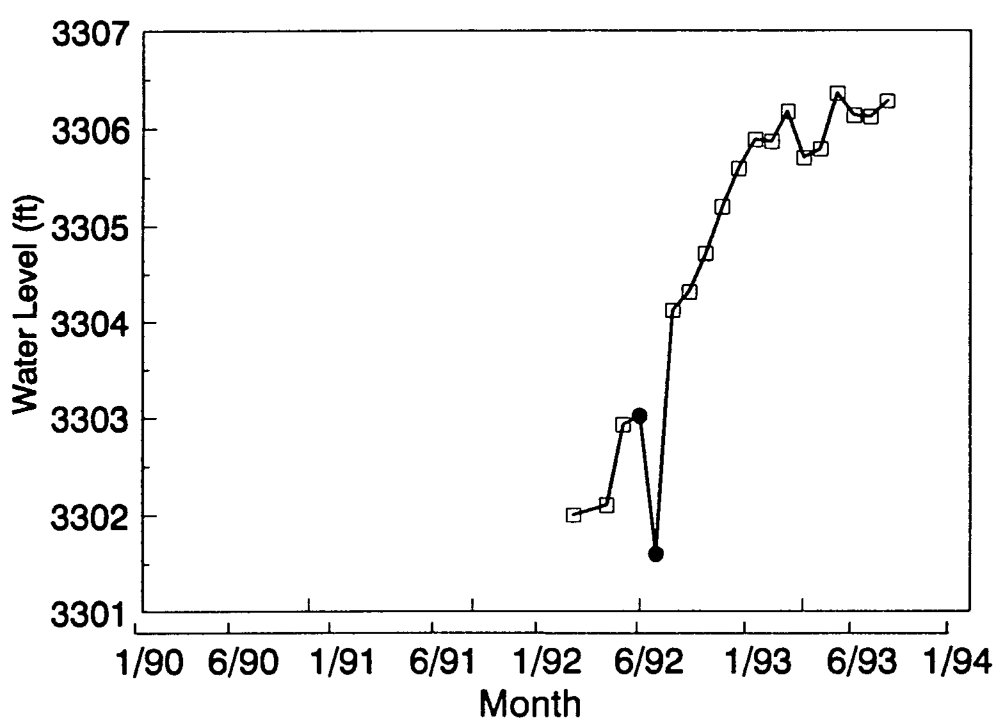
Monthly water level measurements for monitor well AD-4

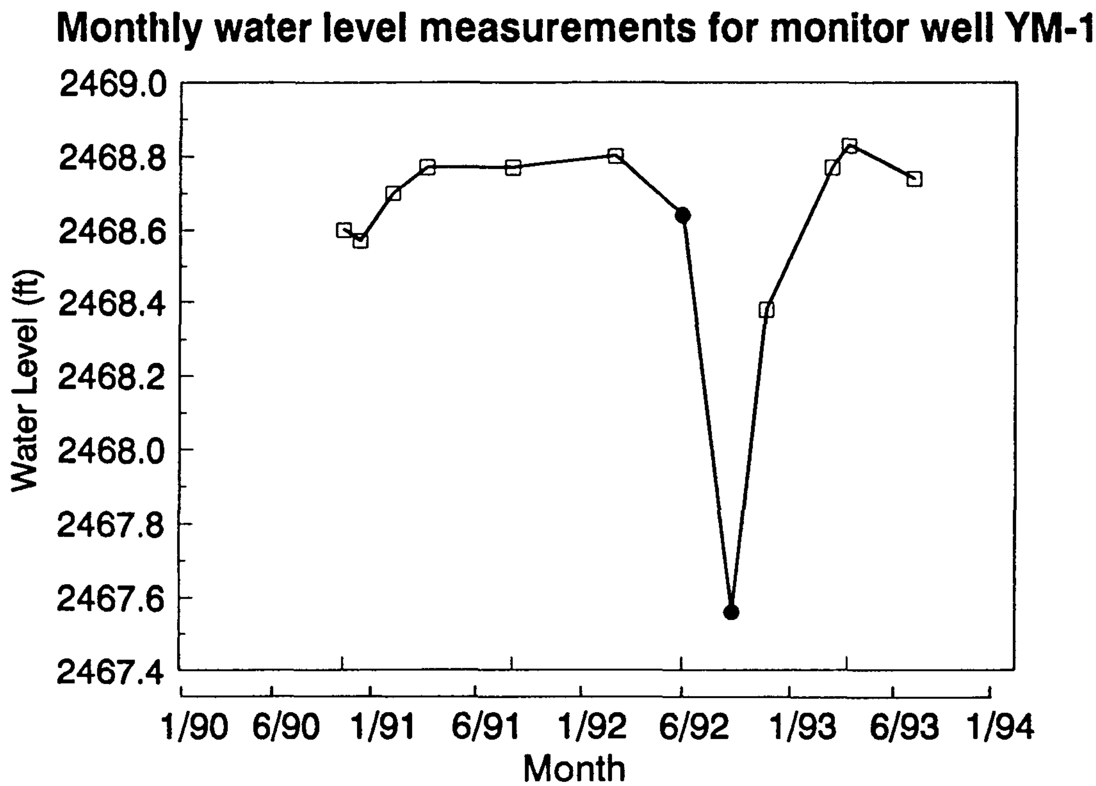


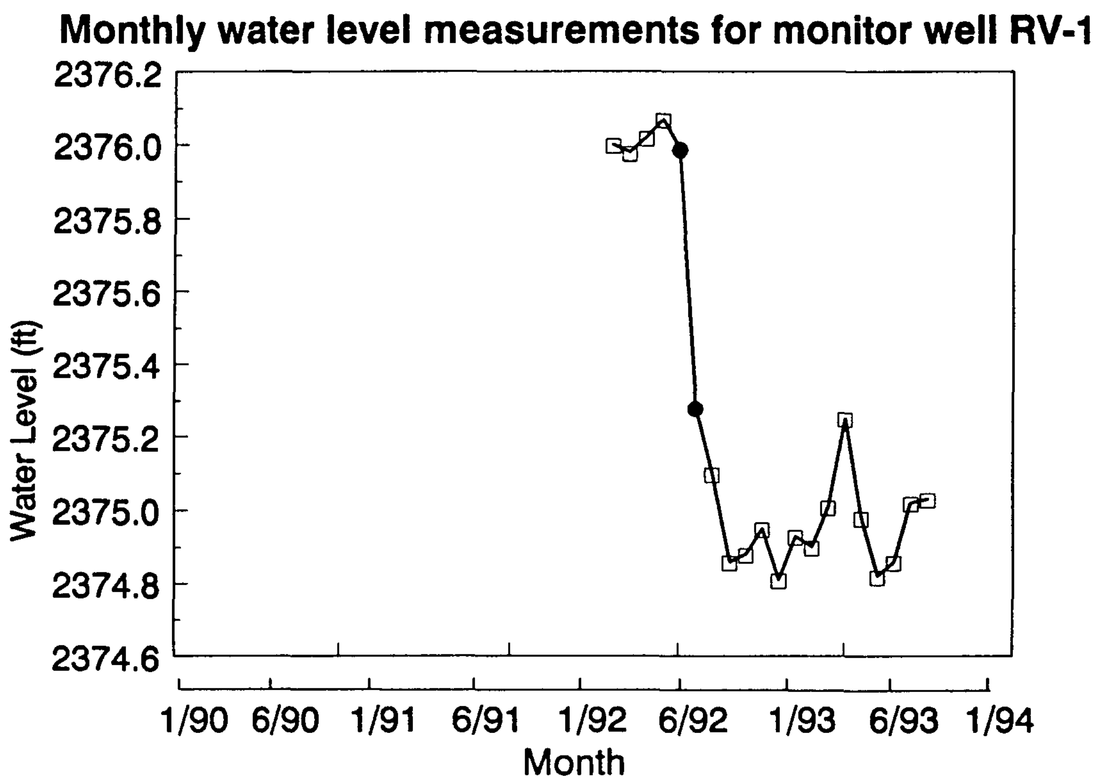
Monthly water level measurements for monitor well AD-13



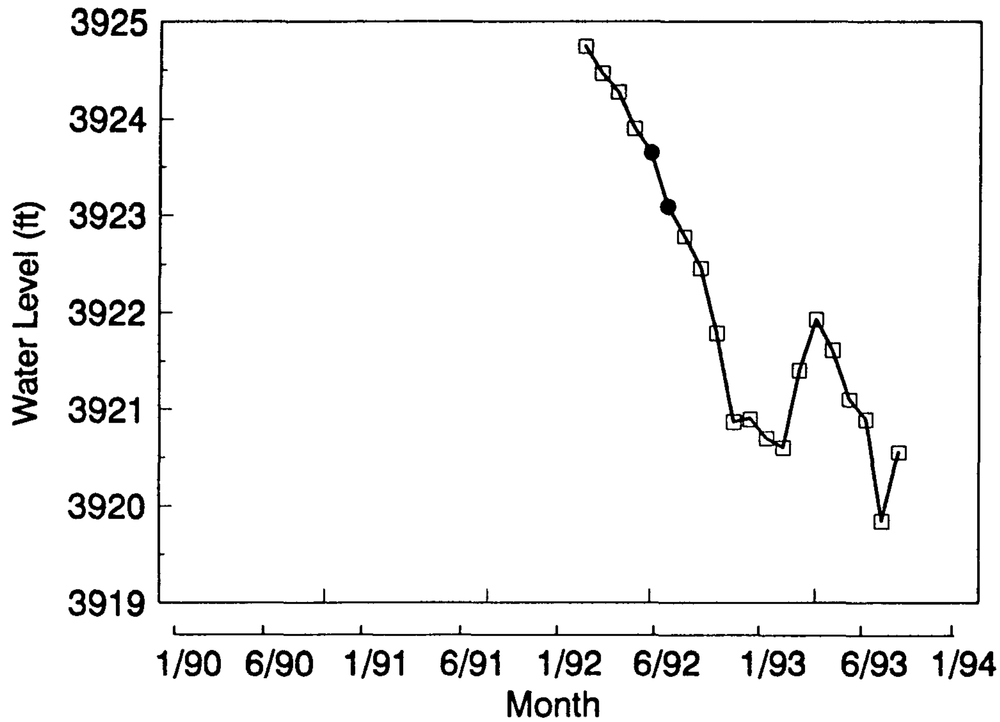
Monthly water level measurements for monitor well CF-1




Monthly water level measurements for monitor well YM-1
Water Level (ft)
2469.0
2468.8
2468.6
2468.4
2468.2
2468.0
2467.8
2467.6
2467.4
1/90
6/90
1/91
6/91
1/92
6/92
1/93
6/93
1/94
Month


Monthly water level measurements for monitor well RV-1
Water Level (ft)
2376.2
2376.0
2375.8
2375.6
2375.4
2375.2
2375.0
2374.8
2374.6
1/90
6/90
1/91
6/91
1/92
6/92
1/93
6/93
1/94
Month

Monthly water level measurements for monitor well CF-3



Monthly water level measurements for monitor well AM-3