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INVESTIGATION OF HYDRAULIC PROPERTIES AND GROUNDWATER LEVELS RELATED TO THE SHEAR ZONE AT THE PROJECT SHOAL SITE

prepared by
Rosemary W.H. Carroll, Karl Pohlmann, Greg Pohll and Todd Mihevc

submitted to
Nevada Operations Office
National Nuclear Security Administration
U.S. Department of Energy
Las Vegas, Nevada

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INVESTIGATION OF HYDRAULIC PROPERTIES AND GROUNDWATER LEVELS RELATED TO THE SHEAR ZONE AT THE PROJECT SHOAL SITE

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ABSTRACT

Project Shoal Area (PSA) is located approximately 50 km southeast of Fallon, Nevada, and in 1963 served as a site for an underground nuclear detonation. As part of an ongoing effort to characterize this site to describe the potential migration of radionuclides, significant hydraulic features have been investigated and the monitoring of observation wells has been conducted. In particular, this report investigates the hydraulic significance of a major shear zone that transects the PSA by developing a three-dimensional model for hypothesis testing and by conducting a pumping test that incorporates wells on each side of this geologic feature. Long-term water level elevations in many monitoring wells are also presented to aid interpretation of water levels during the aquifer test and provide a complete hydrologic picture of the area. The modeling results and the pumping test results both indicate that the shear zone acts as a hydrologic barrier to flow. Long-term well data suggest that most wells are still experiencing recovery from de-watering during drilling, development, and testing and are not at equilibrium.

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LIST OF ACRONYMS

PSA	Project Shoal Area
AMSL	above mean sea level
GPS	global positioning system
RMSE	root mean squared error

INTRODUCTION

The University of Nevada (1965) characterization study of the Project Shoal Area (PSA) recognizes a major shear zone trending N20°E and dipping steeply to the northwest. It is described in these early reports as several hundred feet wide and as "one of the most prominent features of the range." Figure 1a shows the surface expression of the shear zone in relation to several wells drilled in the PSA. Figure 1b provides a cross-sectional view with the dip of the shear zone adjusted to 67° degrees to best match observed clay-rich intervals, interpreted as a fault gouge zone, in well HC-5 (IT Corporation, 2000). This effectively places the producing intervals of HC-5 and HC-8 to the east of the shear zone, while leaving HC-6 and HC-7 to the west.

Figure 2 shows several wells along an east-west trend with static water level elevations marked. While HC-7 and HC-5 are separated by only 50 m in the horizontal direction, water levels between them drop abruptly in excess of 100 m. Research on the hydrologic significance of shear zones shows that fine-grained fault gouge may be two to three orders of magnitude less conductive than the adjacent host rock (e.g., Morrow *et al.*, 1984; Evans, 1997) and depending on the orientation of the fault could provide an important barrier to flow. A model of the Sand Springs Range was constructed for the express purpose of investigating the impacts of the shear zone on head distribution in the vicinity of Shoal (Pohlmann *et al.*, in preparation). Only by incorporating the shear zone into the model were numeric simulations able to appropriately describe heads seen at well HC-5. Simulating a shear zone effectively separated flow into two "compartments," with high heads to the west directing flow northeast toward Fairview Valley, and low heads to the east directing flows further eastward (Pohlmann *et al.*, in preparation).

Purpose and Objectives

Existing data as well as data collected during the installation and testing of new groundwater investigation wells and the tracer test experiment were used to develop the PSA's three-dimensional groundwater flow and transport model. During the tracer test, temporary pumping in well HC-5 appeared to influence water level elevations in well HC-7. It was hypothesized that HC-7 experienced a pressure response due to pumping in HC-5 across the shear zone. The need to understand the hydrologic significance of the shear zone is critical to defining the conceptual model of flow and transport at the site. To assess the hydrologic significance of the shear zone, two major tasks were performed: the shear zone was modeled in three dimensions to evaluate the possibility of a response in well HC-7 to pumping in well HC-5, and a pumping test was conducted in well HC-5 with coincident water levels in all HC wells recorded.

The primary objectives of this report include:

1. Describe the numerical model and its results pertaining to the influence of the shear zone on water levels between HC-5 and HC-7.
2. Evaluate water level elevations in all HC wells during the 2001 pumping test and compare to tracer test data and post-pumping test data.
3. Evaluate long-term water level data pertaining to all HC wells.
4. Establish if there is a hydraulic response to pumping across the shear zone using the analyses listed above.

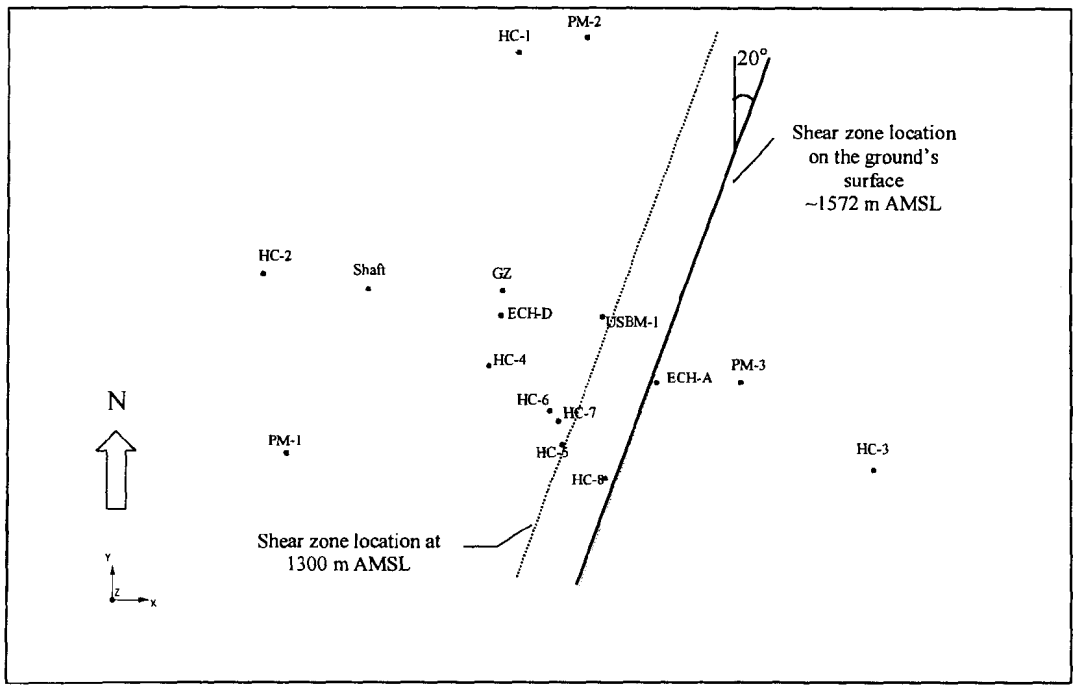

Figure 1a. Planar view of the shear zone in relation to several wells at the PSA.

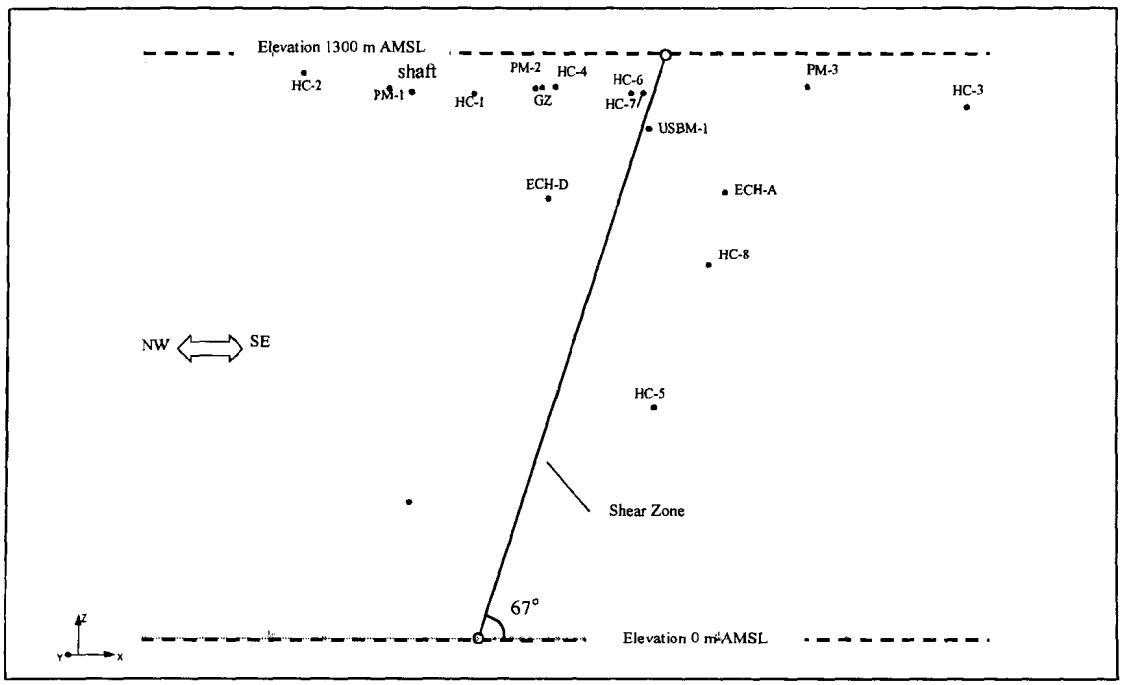

Figure 1b. Cross-sectional view of the shear zone with respect to well locations.

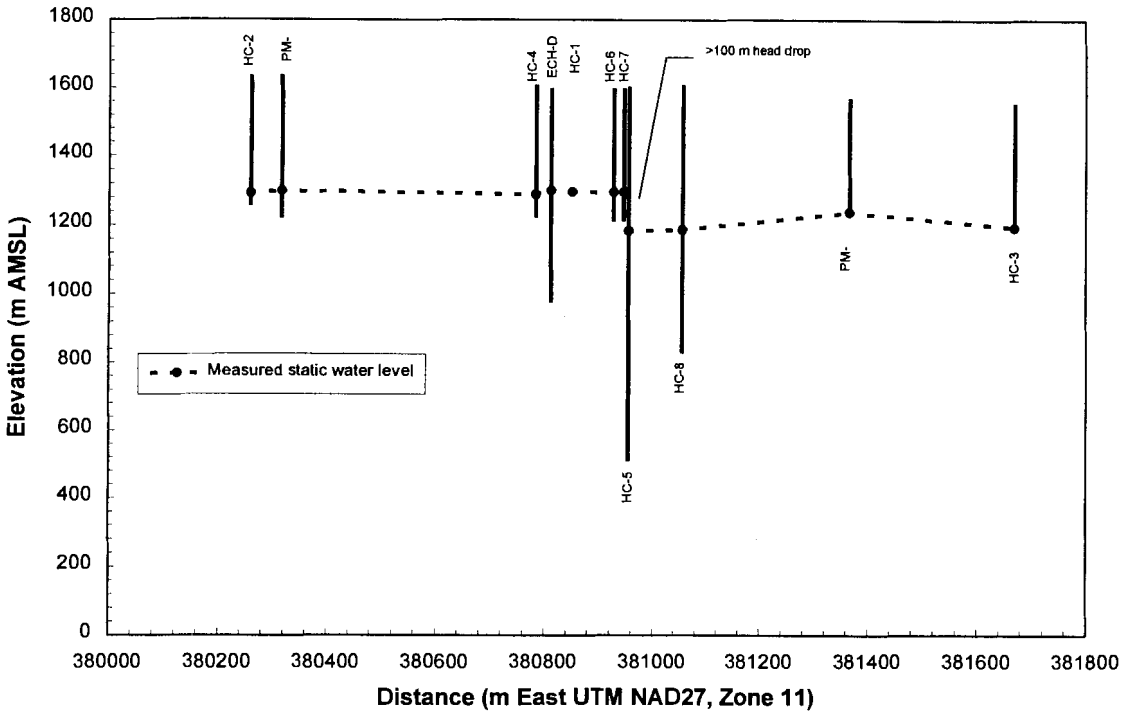

Figure 2. East-west profile through the Shoal site showing measured static water levels and the locations and depths of the wells in which the measurements were made.

SHEAR ZONE MODELING

Pumping in well HC-7 during the 1999-2000 tracer test caused nearly 40 m in drawdown to occur. During the tracer test, well HC-5 was temporarily pumped for sampling purposes. During this time, water levels in well HC-5 dropped about 25 m and HC-7 water levels experienced a sudden drop. It should be noted that HC-7 water levels did not clearly recover following the cessation of pumping in HC-5. A few days later, generator failure caused the pump in HC-5 to turn off. A subsequent rise in water level in HC-7 is believed to have occurred simultaneously. Numerical modeling of the shear zone was then conducted to test the likelihood that the change in HC-7 drawdown slope was due to a pressure response across the shear zone from the pumping of well HC-5.

Numeric Flow Code Description

The three-dimensional finite difference numeric code MODFLOW-96 is used to test the hydrologic significance of the shear zone at the Project Shoal Area. MODFLOW is an established model that is widely accepted by the hydrogeologic community. Its original form was documented by McDonald and Harbaugh (1984) and received significant updates in 1988 (McDonald and Harbaugh, 1988) and in 1996 (Harbaugh and McDonald, 1996a,b). MODFLOW-96 solves the groundwater flow equation provided below (McDonald and Harbaugh, 1988) for head distribution.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) + W = S_s\frac{\partial h}{\partial t} \qquad (1)$$

Variables used by equation (1) are defined as:

K_{xx}, K_{yy} and K_{zz} are values of hydraulic conductivity along the x, y and z axes, (L/T)
h is the potentiometric head (L)
W is a volumetric flux per unit volume representing sources and/or sinks of water with positive values for flow into the groundwater system and negative values for flow out (L^{-1})
S_s is specific storage of the porous material (L^{-1})
t is time (T)

Application of MODFLOW requires that the study area (model domain) be discretized into a grid of rectangular blocks so that the groundwater flow equation can be solved for hydraulic heads at the center of each block. Equation (1) represents the most general form of the groundwater flow equation. When equation (1) is used in conjunction with initial and boundary conditions, it describes a fully three-dimensional, transient flow system within a heterogeneous and anisotropic medium. For this study, heterogeneous conditions are maintained but isotropic conditions are assumed (i.e., $K = K_{xx} = K_{yy} = K_{zz}$).

Domain Description

Figure 3 shows the areal extent of the model domain with wells HC-5 and HC-7 marked. The model grid is rotated 20° from north to align the y-axis parallel and the x-axis perpendicular to the shear zone at the PSA. Grid dimensions are set at 1,200 m in the x-direction and 600 m in the y-direction. Cell refinement was accomplished by setting the base cell size to 5 m in both the x and y-directions at each well location and allowing an increase in cell bias of 1.2. Consequently, there are 60 columns and 50 rows. The maximum cell size in the x-direction equals 50.8 m, while the maximum cell size in the y-direction attains 26.9 m. The model is comprised of 16 active layers with each layer having a vertical dimension of 55 m. The top of the uppermost active layer is situated at 1,240 m AMSL while the base of the model is at 360 m AMSL. Well HC-7 is located in the uppermost active layer, while well HC-5 is located in layer 12.

The central line of the shear zone expressed on the ground surface (~1,572 m AMSL) was defined in the field using global positioning system (GPS). The plane of the shear zone was subsequently defined by adjusting the dip to 67 degrees to match observed depths of the fault gauge in wells HC-7 and HC-5 (IT Corporation, 2000). The shear zone is assumed to contain a core comprised of fine-grained fault gouge as well as a fractured and damaged outer skin. While neither data nor previous modeling studies indicate that a damaged zone exists at PSA, it is included in this study to to enhance the hydraulic connection with simulated breaks in the shear zone core

Boundary Conditions, Initial Conditions

Constant head boundary conditions are taken from interpolated head values of a preliminary three-dimensional model of the northern Sand Springs region. These boundary conditions infer a recharge value of 0.62 cm/yr used in the Sand Springs model, making it redundant to apply recharge to the top of this particular model's domain. Initial conditions for the transient model simulation were obtained by running the model under steady-state conditions to establish the equilibrium head distribution given no pumping in either well HC-5 or well HC-7.

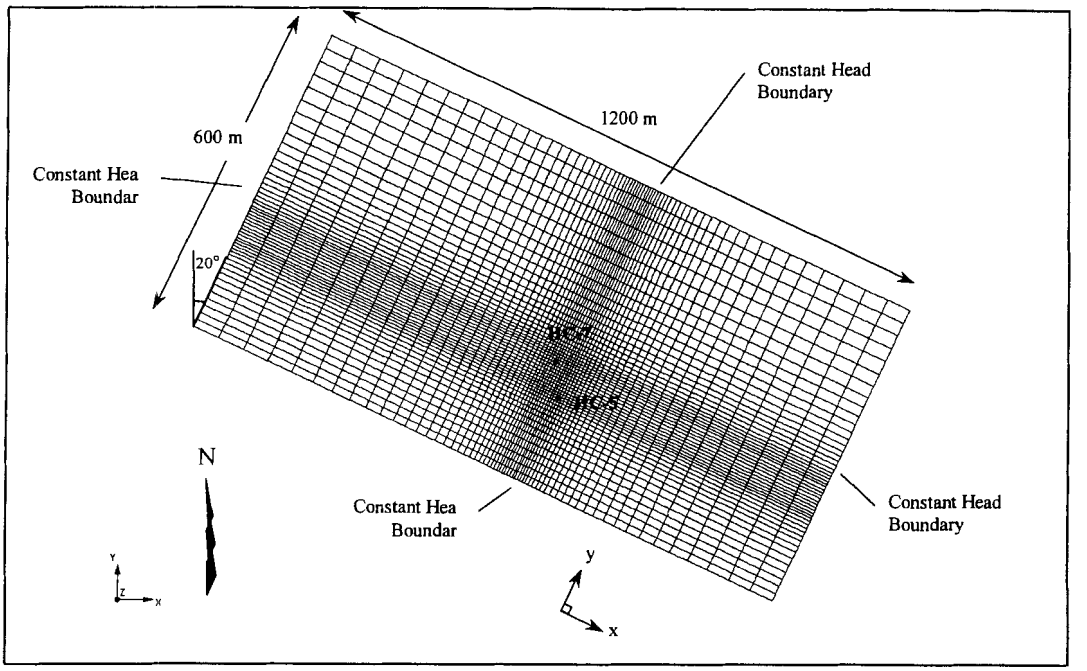

Figure 3. Top layer of modeled grid with wells HC-7 and HC-5 marked.

The primary storage coefficient and secondary storage coefficient are assigned values of 0.01 and 1.0 x 10^{-5} to best represent the region's porosity and confined aquifer conditions, respectively. The hydraulic conductivity of the shear zone core (K_C) and the hydraulic conductivity of the rubble zone (K_R) are given the values of 2.6 x 10^{-7} m/d and 0.013 m/d, respectively, and are obtained from previous modeling efforts. While no hydraulic data exist for either the core or the rubble zone of the PSA shear zone, the assigned values represent best estimates from an extensive evaluation of different shear zone configurations and the ability to match hydraulic heads in several of the area's observation wells (Pohlmann *et al.*, in preparation). The hydraulic conductivity of the surrounding granite rock (K_g) is used as a calibration parameter. It should be noted that hydraulic conductivity is assumed isotropic throughout the model, including within the shear zone. Therefore, the vertical leakance assigned to each cell is equal to the hydraulic conductivity of that cell. All assigned parameter values as well as calibrated parameter values are presented in Table 1.

Four separate stress periods are designated over the 210 days of the model simulation. The first stress period lasts 90 days and allows no pumping. This was done to further ensure that equilibrium water levels are attained prior to pumping. The second stress period begins on day 90 and lasts until day 150. It is during this period that pumping is initiated in well HC-7 at 3 gal/min to mimic tracer test conditions. Pumping in well HC-7 continues for the duration of the simulation. After two months of pumping HC-7, the third stress period begins with pumping in well HC-5 at 5 gal/min. Pumping in HC-5 lasts for 30 days and is then turned off on day 180. The fourth stress period of 30 days maintains the pumping rate in well HC-7 but allows recovery of well HC-5.

Model Calibration

As already mentioned, the surrounding granite hydraulic conductivity (K_g) both to the west and east of the shear zone is the designated calibration parameter. K_g is adjusted to a value of 0.002 m/d as the best match to the 40 m of drawdown experienced in well HC-7. This value is somewhat lower than the geometric mean of the seven pumping tests conducted in the HC wells at Shoal (Mihevc *et al.*, 2000), slightly higher than the effective K used in a regional two-dimensional model of Fairview Valley and the Sand Springs Range and nearly equal to the assigned value used in the three-dimensional northern Sand Springs model (Pohlmann *et al.*, in prep.).

Earlier three-dimensional modeling studies of the northern Sand Springs area identified the thickness of the shear zone as an important factor in predicting the head drop across the shear zone. A shear zone core thickness of 30 m (from the central plane of the shear zone, thus making the shear zone 60 m thick from edge to edge) was used to balance observed values in the field as well as maximizing head drop between HC-7 and HC-5. The rubble zone was assigned a thickness of 15 m on each side of the shear zone core. This thickness was chosen to keep the shear zone from encroaching on well HC-7, since no indication of either a rubble zone or fault gouge are seen in its geophysical logs (IT Corporation, 2000).

Table 1. Values used to define the shear zone model.

Parameter	Value	Reason
S_s	0.01/0.00001	Set to equal porosity (0.01) and a confined situation (1.0×10^{-5})
K_g	2.0×10^{-3} m/d	Adjusted to match ~40 m drawdown in HC-7
K_C	2.6×10^{-7} m/d	Same as previous study, width adjusted (30 m) to get largest difference between HC-7 and HC-5 without causing severe drawdown in HC-7
K_R	1.30×10^{-2} m/d	Same as previous study, with adjusted (15 m) so the shear zone just misses encroaching on HC-7
Leakance	K	Assume isotropic conditions

Results

Simulated water levels in wells HC-5 and HC-7 are shown in Figure 4a. Included are data collected in well HC-7. While the calibrated value of K_g provides the correct amount of drawdown in well HC-7, it predicts a faster response in the drawdown than observed. Adjustments to specific storage did not alter the immediacy of simulated drawdown. The model's inability to match drawdown rates in HC-7 is due in part to inconsistencies in pumping rates (and generator failures). However, the greatest source of error may be in the model's homogenous representation of the granite host rock, which in reality is dissected by several fractures and heterogenous in nature. Drawdown in well HC-7 appears unaffected by putting HC-5 on-line at 5 gpm. Simulated drawdown in well HC-5 is estimated at about 40 m, which is larger than the observed 25 m. If it is assumed that the granite rock to the east of the shear zone has a different hydraulic conductivity than the granite to the west of the shear zone, it is possible to match the observed drawdown in HC-5. In such a scenario, K_g to the west lowers slightly to 0.0015 m/d, while K_g to the east rises to 0.006 m/d. While the addition of the extra calibration parameter allows one to match heads, results concerning the effects of the shear zone on hydrologic response in well HC-7 due to pumping in well HC-5 remain the same. Also, no data support different

hydraulic conductivities to the east and west of the shear zone. For these reasons only results pertaining to a single K_g value are provided in detail.

Given no response is detected with the model in well HC-7 with pumping in HC-5, different scenarios of shear zone continuity were tested to see if a response could occur with various breaks in the shear zone. Scenarios include a break in the upper shear zone (i.e., no shear zone in the uppermost two active layers), a larger break in the upper shear zone (i.e., no shear zone in the uppermost four active layers), a break in the lower shear zone (i.e., no shear zone in layers 11 and 12) and finally, no shear zone modeled. All results for drawdown in well HC-7 are presented in Figure 4. Note that no drawdown curve is shown for a break in the lower shear zone. This is because its distance from well HC-7, which resides in the top layer, causes no response that is different from the "no break in the shear zone" scenario, and so is excluded from the analysis. What is discovered is that the larger the break in the shear zone, the more drawdown is experienced in well HC-7 (Fig 4b) and the greater the change in slope in drawdown when pumping occurs in well HC-5 (Fig 4c).

While the breaks in the shear zone contribute more drawdown in HC-7, they are not able to replicate the manner of the sudden drop in water level observed in Figure 4a nor do they simulate any recovery in HC-7 corresponding to HC-5 pump being shut off. Simply matching drawdown is not a problem with the reasonable value of K_g already used. Therefore, the model suggests that HC-5 and HC-7 are not hydrologically connected and that the sudden drop in water levels in HC-7 when pumping began in HC-5 is merely coincidental. However, the hypothesis that a pressure response does occur between HC-5 and HC-7 is further tested in the field as described in the following section describing the pumping test.

PUMPING TEST

Configuration

Pumping began in well HC-5 on February 2, 2001, at 14:40 and continued until February 12, 2001, 12:49. Well HC-5 was instrumented with a transducer and datalogger with data tabulated every minute. Discharge from well HC-5 was continuously monitored with a totalizer (maintains a running total of gallons pumped) and was checked manually via bucket and stopwatch. Observation wells HC-6 and HC-7 were also instrumented with transducers and dataloggers. Data were retrieved every five minutes in well HC-6 and every 10 minutes in HC-7. Periodic manual water level measurements were collected in all wells (HC-1, HC-2, HC-3, HC-4, HC-5, HC-6, HC-7 and HC-8).

Transducer data obtained from HC-5 were corrected by subtracting continuous barometric pressure readings from the stage data. This was necessary because the transducer placed in HC-5 was unvented. On the other hand, transducers in wells HC-6 and HC-7 were able to auto-calibrate for barometric pressure and no adjustment was necessary. All water level data (datalogger and manual readings) were adjusted to account for borehole deviations. Data were then converted into an elevation reading (m AMSL) by taking into consideration the top of the well casing.

If available, data pertaining to pre- and post-tracer-test conditions are presented to assess a well's recovery from the tracer test. Note that the tracer test was initiated immediately after two preliminary aquifer pumping tests in HC-7 were conducted during October 4, 1999, and October 11, 1999. Injection for the tracer test began at well HC-6 in early November 1999 while pumping

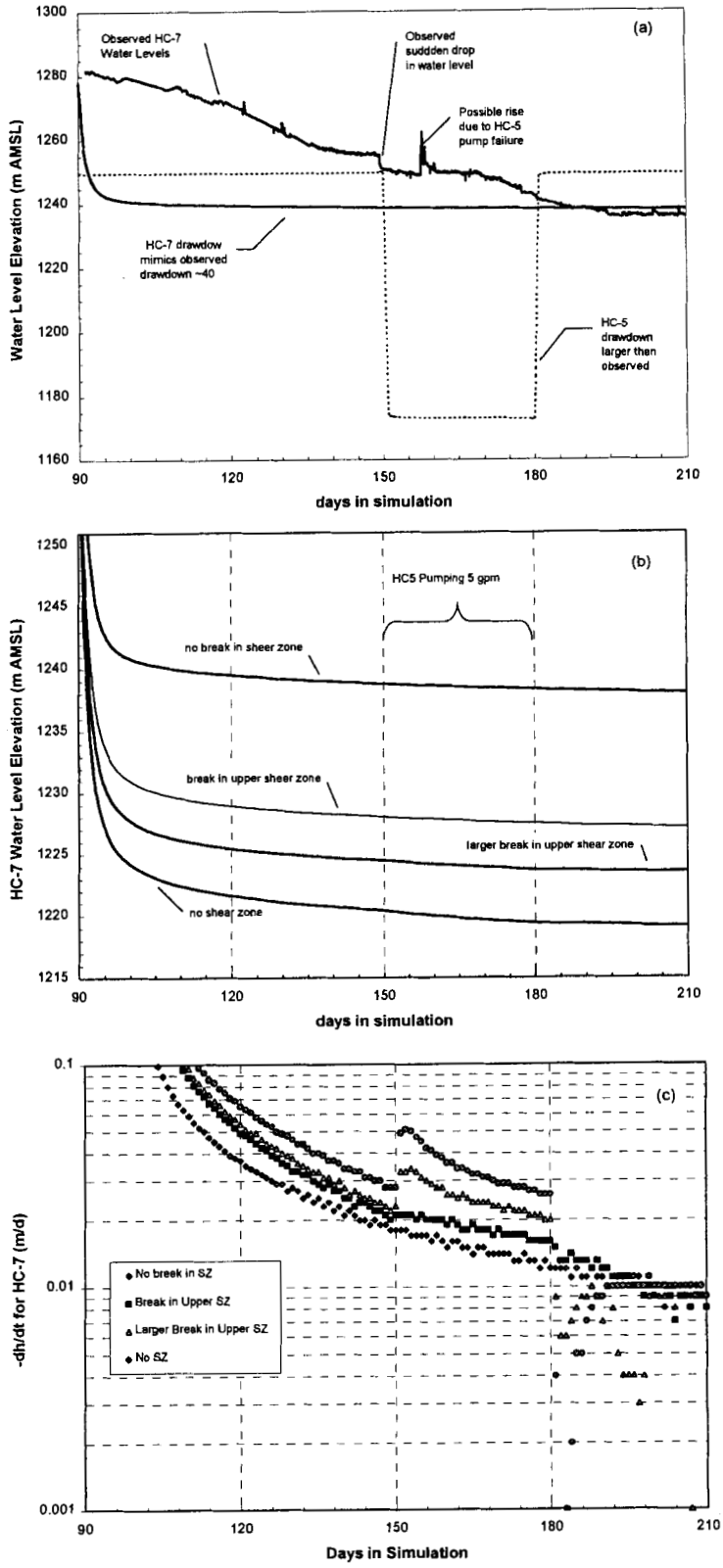

Figure 4. Simulated results for (a) drawdown in HC-7 and HC-5 compared to observed HC-7 data, (b) drawdown in HC-7 for several different scenarios of shear zone continuity and (c) values of –dh/dt for several different scenarios of shear zone continuity.

occurred in well HC-7. No interruption in the pumping of HC-7 occurred between the October 1999 pumping tests and the subsequent tracer test to ensure steady-state conditions. The tracer test lasted until late September 2000, at which point pumping in HC-7 was halted. Also provided are water level measurements collected on May 16, 2001, and July 27, 2001. These data allow an assessment of each well's recovery toward its static water level.

Water Level Elevations

Data collected in each of the HC-wells are presented below. Long-term data records are presented for each well in a series of figures at the end of the discussion regarding the 2001 aquifer test.

Well HC-1

While transducer data were collected in well HC-1 during 1996 and 1997, data were only manually collected during 1999, 2000 and 2001. This information is presented in Figure 5. Water levels in HC-1 prior to the 1999-2000 tracer test experiment were considerably lower than water levels recorded since September 2000. No information regarding HC-1 was obtained during the February 2001 pumping test, but data collected after the pumping test show a gradual increase in water level elevation.

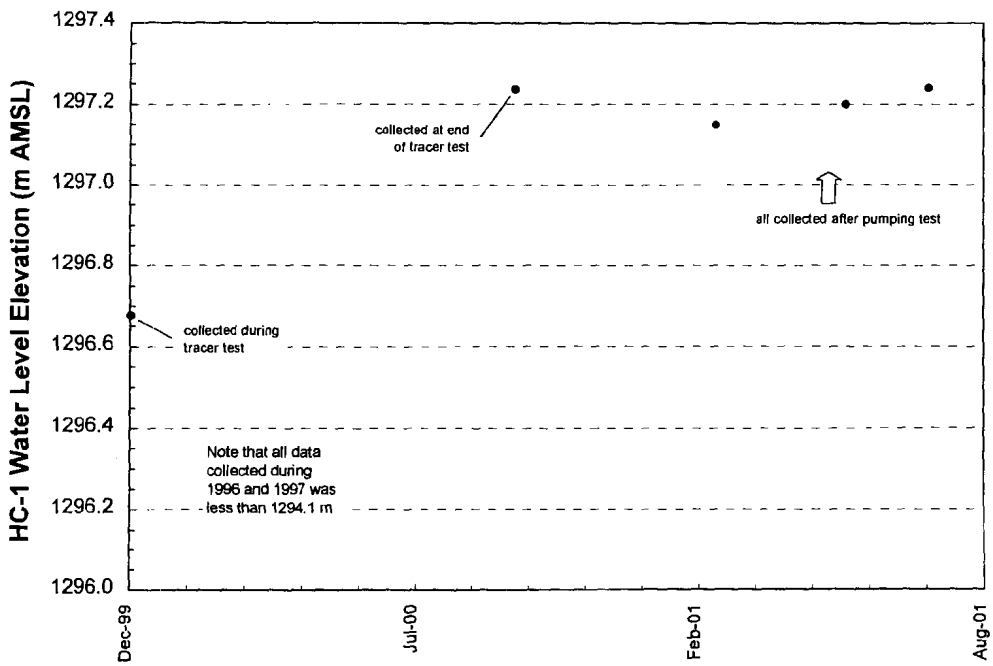

Figure 5. HC-1 water level elevations collected before and after the 2001 pumping test.

Well HC-2

Similar to well HC-1, water levels in HC-2 are significantly lower prior to 1998. Presented in Figure 6 are manually collected water level data collected during the tracer test experiment, at the end of the tracer test experiment and after the 2001 aquifer pumping test. An increasing trend is exhibited in water level elevations beginning in October 1996 and continuing until July 2001.

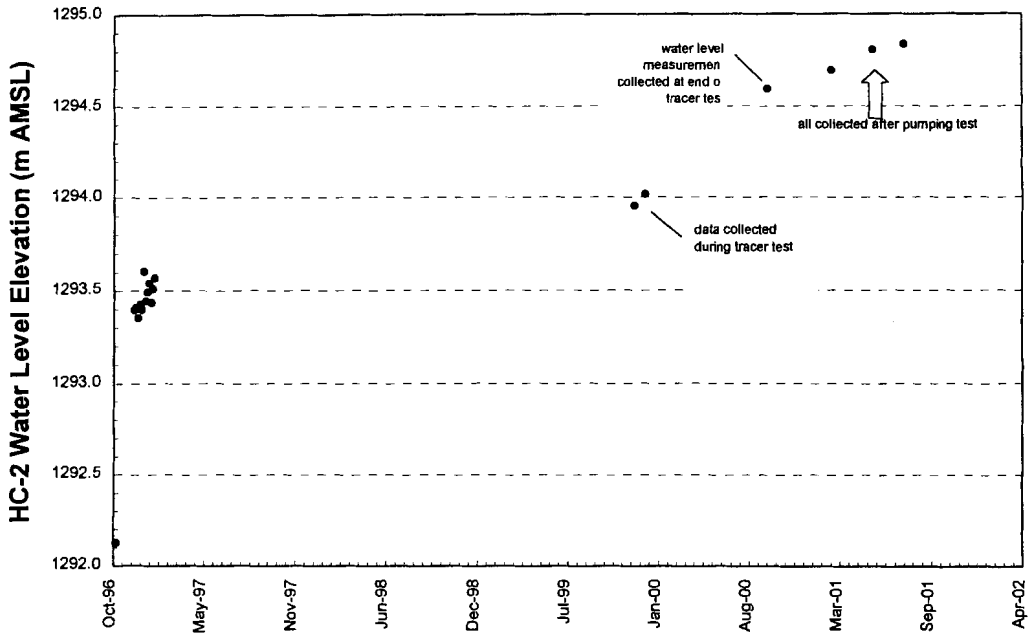

Figure 6. HC-2 water level elevations collected before and after the 2001 pumping test.

Well HC-3

While not shown in Figure 7, water level data collected in well HC-3 during November 1996 were 1,226 m AMSL, approximately 33 m higher than data collected during 1999, 2000 and 2001. However, these heads drop off significantly to 1,188 m AMSL by May 1997, approximately 4 m less than initial water level readings taken in 1999 prior to the tracer test experiment. Such large deviations in water level are not understood. While no data were collected in well HC-3 during the pumping test, water levels are in general increasing. A dip in water levels, however, was experienced between the end of the tracer test and the end of the pumping test. While HC-3 lies on the same side of the shear zone as the pumping well HC-5, not enough data exist to correlate the two responses.

Well HC-4

Few data exist for well HC-4 because its downhole configuration prevents transducer or water-level probe use (there is a submersible pumping in the well with no access tube). No data exist during or following the tracer test experiment in 1999-2000. Likewise no data exist under pumping test conditions. Data that were collected during 1996 and 1997 are highly variable. A single data point collected prior to the tracer test experiment showed water level elevation in well HC-4 to equal 1,289.51 m AMSL.

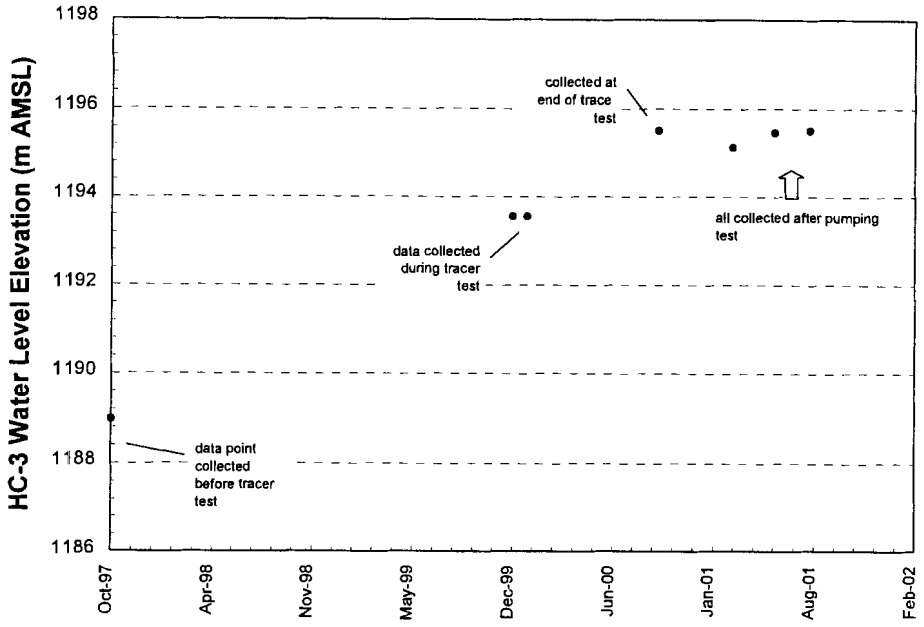

Figure 7. HC-3 water level elevations collected before and after the 2001 pumping test.

Well HC-5

As already mentioned, well HC-5 was the pumping well for the 2001 aquifer pumping test. Pumping rates presented in Figure 8 compare totalizer readings with manually collected rates (bucket and stopwatch technique). Totalizer readings appear somewhat erratic with two data points indicating much lower flow rates than manual measurements would suggest. The second of these low readings, taken late in the afternoon on February 10, 2001 is attributed to the totalizer being plugged with sand. On average, totalizer readings measured a flow rate of 6.07 gal/min, while hand measurements indicate a flow rate of 6.18 gal/min. Relative error shows that on average, the totalizer underpredicts manual measurements by 0.18 gal/min. This error is significantly reduced to underpredicting by 0.035 gal/min if the data points collected on February 5 and February 10 are discarded.

Figure 9 shows water level measurements collected in well HC-5. Manually collected pre- and post-pumping-test water level measurements show little deviation from water level measurements collected before and after the tracer test experiment. This suggests that well HC-5 is at static equilibrium prior to pumping and re-obtains equilibrium water levels fairly quickly.

Well HC-6

Continuous data and manually collected data pertaining to well HC-6 are shown in Figure 10. For reference, data collected prior to and during the 1999-2000 tracer test experiment as well as post-pumping-test data are listed within the Figure. Tracer test information shows that initial water levels in well HC-6 were nearly 6.5 m higher than observed water levels prior to the pumping test on February 1, 2001, and still 5 m higher than water levels collected during the summer following the pumping test. While no data exist for well HC-6 to describe the lowest achieved water levels at the end of the tracer test, data collected on May 15, 2000, show a drop in head of approximately 5 m. Undoubtedly, water levels dipped another 3-5 m between May 15, 2000, and the end of the tracer test on September 26, 2000. Given this information and the upward

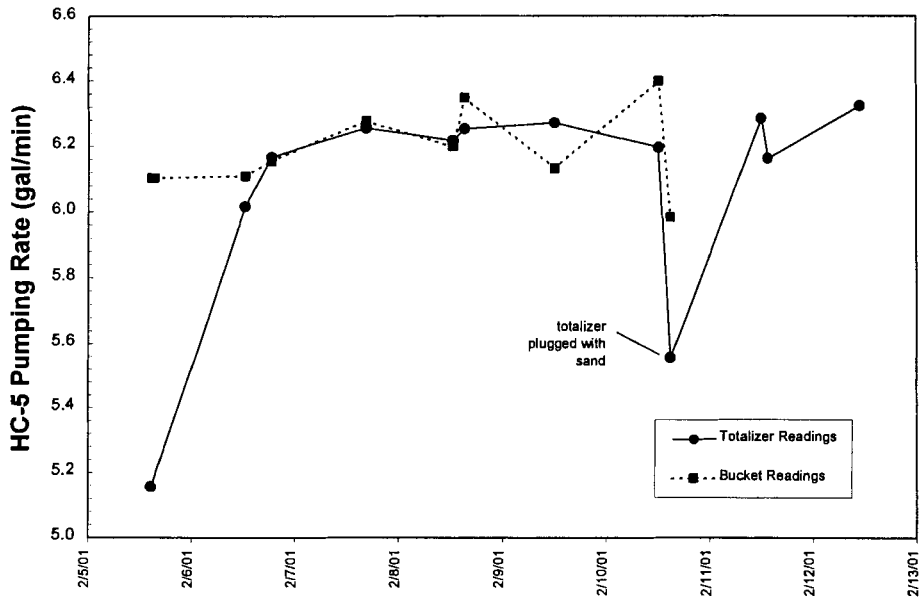

Figure 8. HC-5 pumping rates taken during the 2001 pumping test.

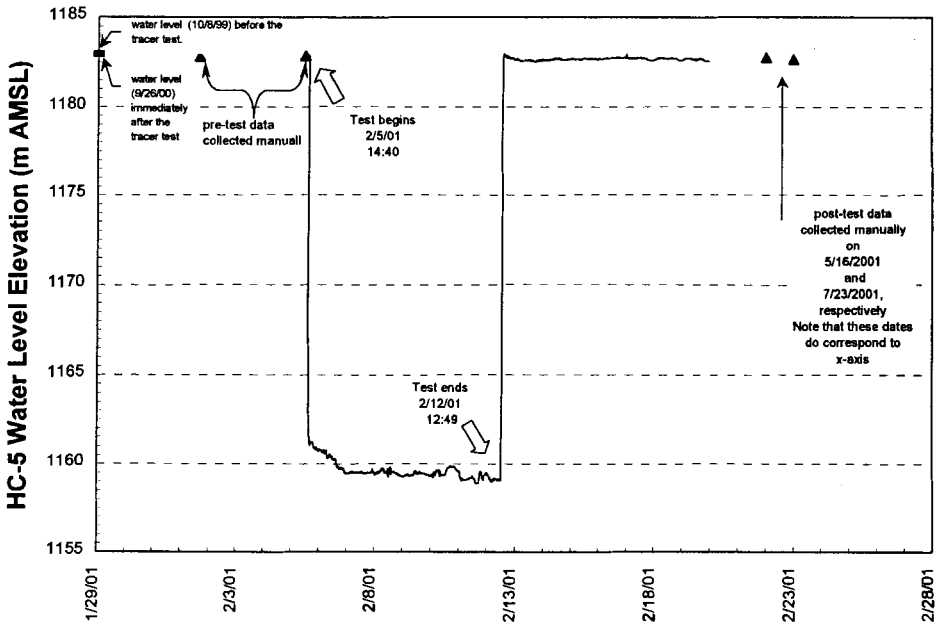

Figure 9. HC-5 water level elevations collected before, during and after the 2001 pumping test.

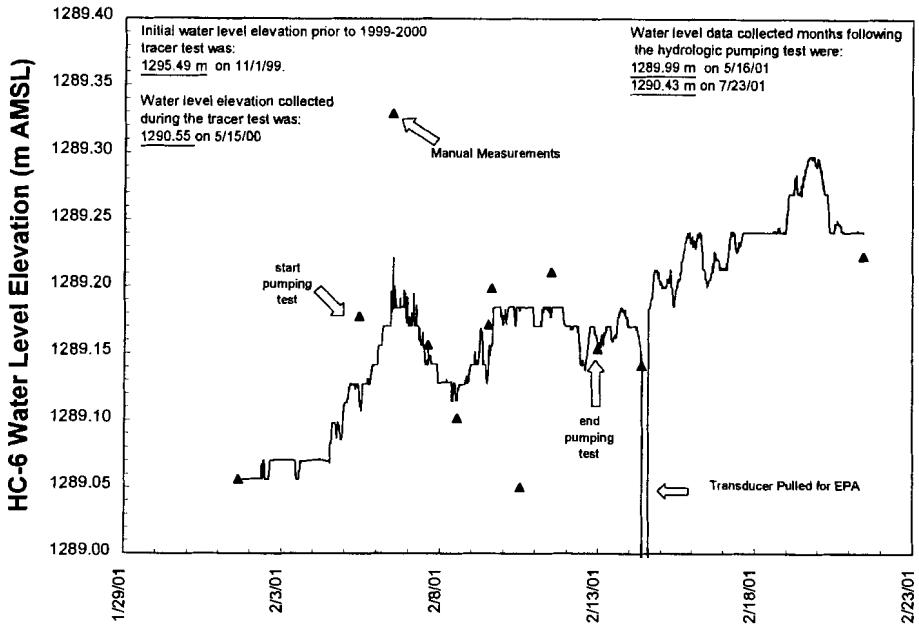

Figure 10. HC-6 water level elevations collected before, during and after the 2001 pumping test.

trend in pumping test water levels, it appears that water levels in HC-6 are still recovering from the tracer test experiment. A comparison between transducer and manual water level elevations reveals that, despite the very low manual reading taken on February 10, manual water level measurements are, on average, 0.014 m higher than those obtained via the transducer. Absolute error shows deviations averaging 0.042 m, while the root mean squared error (RMSE) equals 0.063 m.

Well HC-7

Figure 11 shows water level measurements taken before, during and after the pumping test from well HC-7. Also listed in the figure are water level measurements obtained before the original 1999 aquifer test as well as water levels after the tracer test. Static water levels in HC-7 are estimated to equal 1,295.78 m AMSL. Drawdown experienced in well HC-7 by the end of the tracer test was a substantial 63 m. Water level recovery within HC-7 is approximately 50 m by the start of the pumping test in February 2001. Continued recovery in the water levels is seen throughout the pumping test as well as beyond the test with water levels attaining 1,287.55 m AMSL by July 23, 2001, which is still 9 m lower than equilibrium. Data discrepancies exist between continuous and manual measurements. In all cases, manual reading are larger than those recorded on the datalogger. On average, this error is 0.11 m. While water levels differ between the two methods of collection, the rate of well recovery is essentially the same.

Well HC-8

Manual water level measurements for well HC-8 are presented in Figure 12. Also included is a reading taken before and during the tracer test as well as two data points collected several months after the pumping test. Data during the pumping test show a downward trend, but the amount of scatter may negate any possible correlation seen between HC-5 and HC-8 during the pumping test.

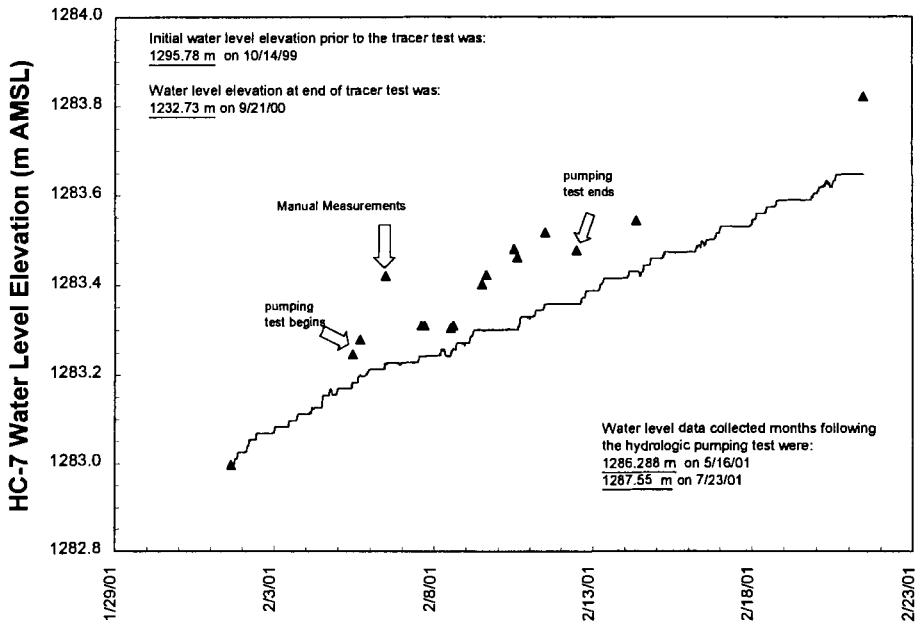

Figure 11. HC-7 water level elevations collected before, during and after the 2001 pumping test.

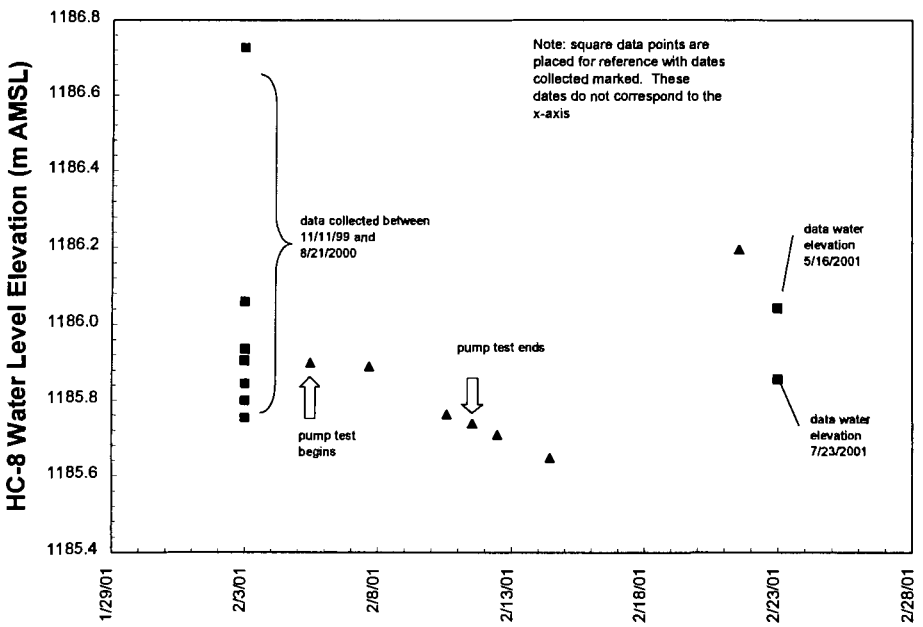

Figure 12. HC-8 water level elevations collected before, during and after the 2001 pumping test.

WATER LEVEL COMPARISON BETWEEN PUMPING TEST WELLS

Figure 13 provides a comparison of water level elevations between the pumping well HC-5 and each of the critical monitoring wells HC-6, HC-7 and HC-8. Well HC-8 appears to show a slight response to the pumping of well HC-5. Drawdown in HC-8 occurs two days after pumping begins and then water levels begin to rise two days after the pump in HC-5 is turned off. While a

response in well HC-8 was anticipated given that it lies on the same side of the shear zone as HC-5, this response may be somewhat artificial given the scatter in data points collected both before and after the pumping test.

No response is seen between wells HC-5 and HC-7, suggesting that the shear zone acts as a hydrologic barrier to flow. On the other hand, a slight response may be detected in well HC-6. It could be argued that the slope of recovery lessens in HC-6 a day or two after pumping begins and resumes a day or two after pumping is turned off. However, this change in slope is quite small, and somewhat erratic. Further investigation shows the change in head over one day time steps (Figure 14) has no definitive pattern or relationship with the pumping in well HC-5. Given no response is seen in wells HC-6 and HC-7, it is believed that no hydrologic connection exists across the shear zone.

LONG-TERM WATER LEVEL RECORDS

Water level data for the HC wells has been periodically collected since the wells were drilled. For HC-1, -2, -3, and -4, their records extend back to 1996; HC-5, -6, -7, and -8 were drilled in 1999. Many of these records exhibit substantial long-term recovery from de-watering experienced during drilling, development, and testing. As a result, pre-1999 data were not included in the previous graphs so the vertical scale could focus on water level responses to the HC-5 aquifer test. Figures 15 through 22 present the full data records for the HC wells.

CONCLUSIONS

While initial observations may have suggested a possible pressure response across a large shear zone in well HC-7 due to pumping in well HC-5, modeling and additional field test results indicate that this is not likely. Any response seen in well HC-7 is more likely due to other factors. For example, it is possible to change drawdown slope if water levels cross a fracture that transects the borehole. Long-term water level data place tracer test and pumping test information in a bigger picture context. Data extending back to 1996 in several wells show that most of these wells are still recovering from initial drilling and development and are not at equilibrium. Data collected in well HC-7 also show that it is still recovering from the tracer test conducted from November 1999 to September 2000. The increasing trend in water levels experienced in well HC-7 is not interrupted by pumping in HC-5. At first glance, it appears that well HC-6, which lies on the opposite side of the shear zone from the pumping well HC-5, experiences a change in drawdown slope given a two-day lag. This would suggest some sort of hydrologic connection with well HC-5 across the shear zone. However, upon closer inspection, this correlation is not significant. To conclude, both numeric modeling of the shear zone and the evaluation of water level data collected during a hydrologic pumping test all indicate that the shear zone acts as a significant barrier to flow.

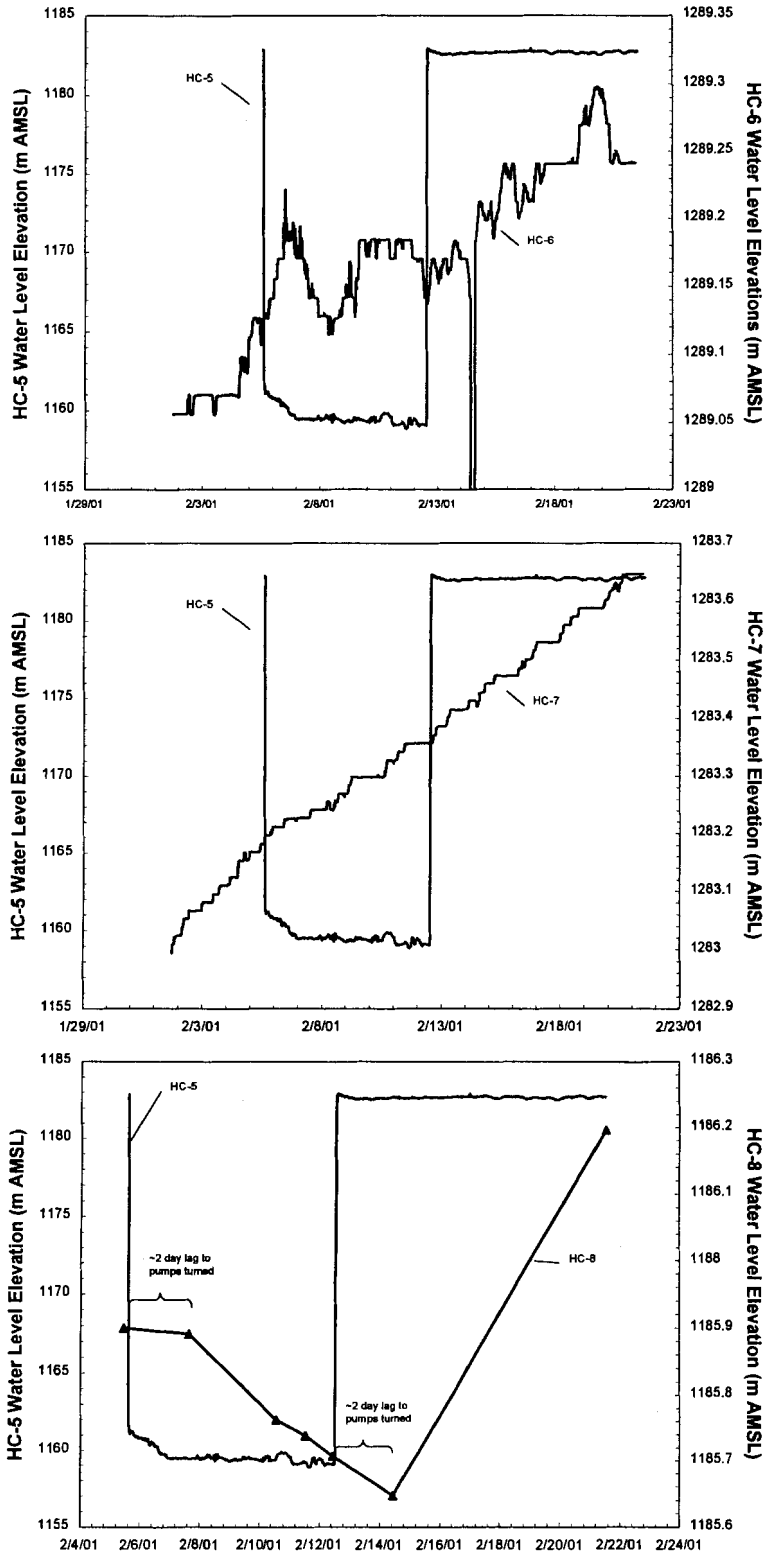

Figure 13. Comparison of water levels between the pumping well HC-5 and the observation wells (a) HC-6, (b) HC-7 and (c) HC-8

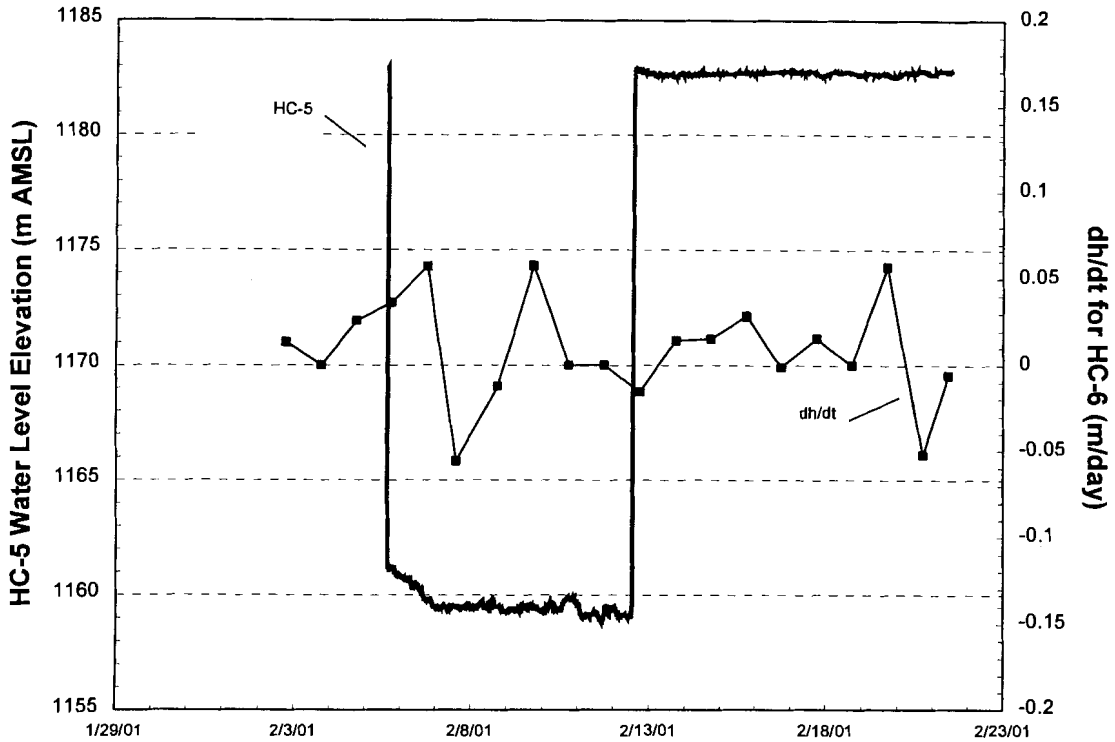

Figure 14. Comparison of dh/dt, taken on a one-day timestep, with respect to drawdown in well HC-5.

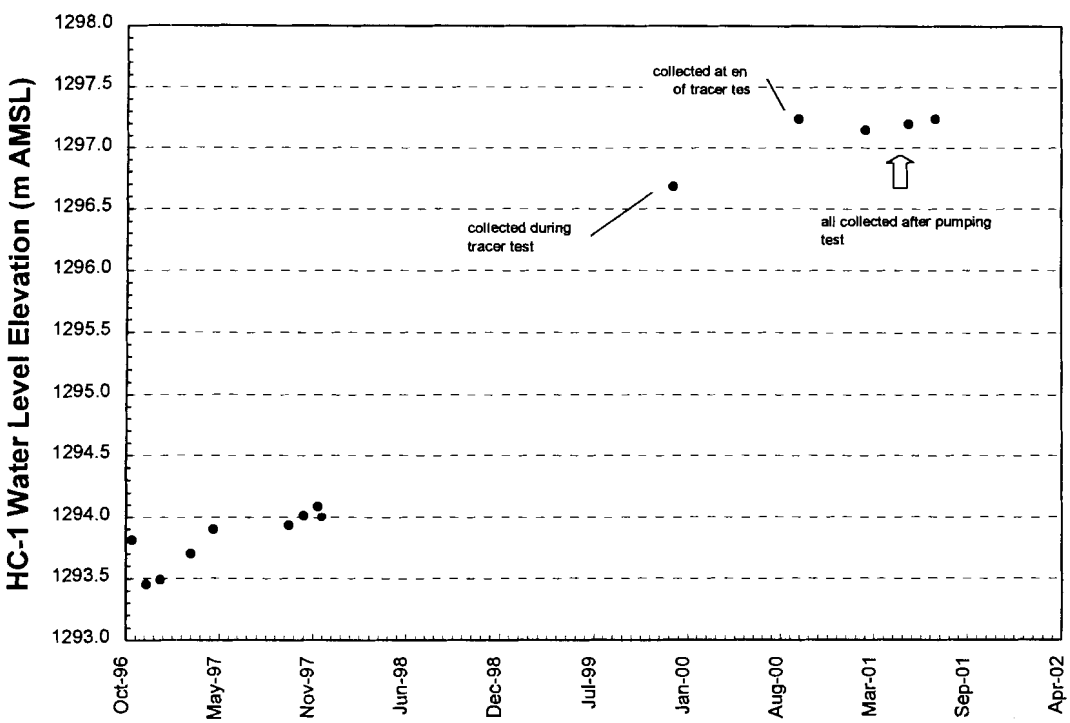

Figure 15. HC-1 water level elevations collected from October 30, 1996, to July 13, 2001.

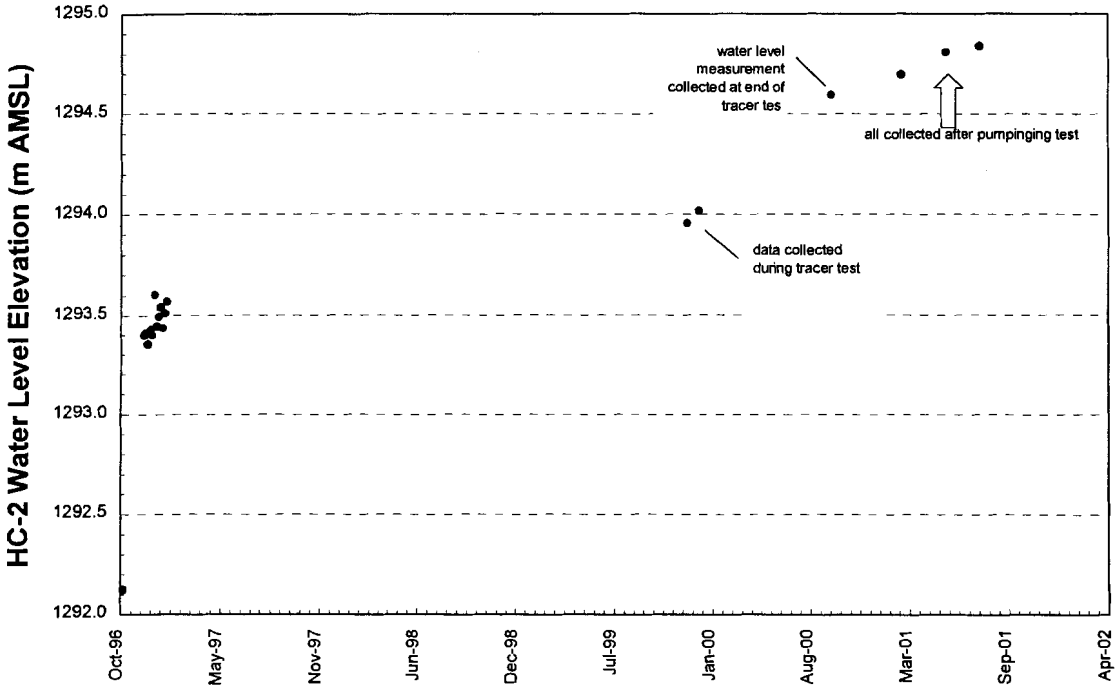

Figure 16. HC-2 water level elevations collected from October 22, 1996, to July 23, 2001.

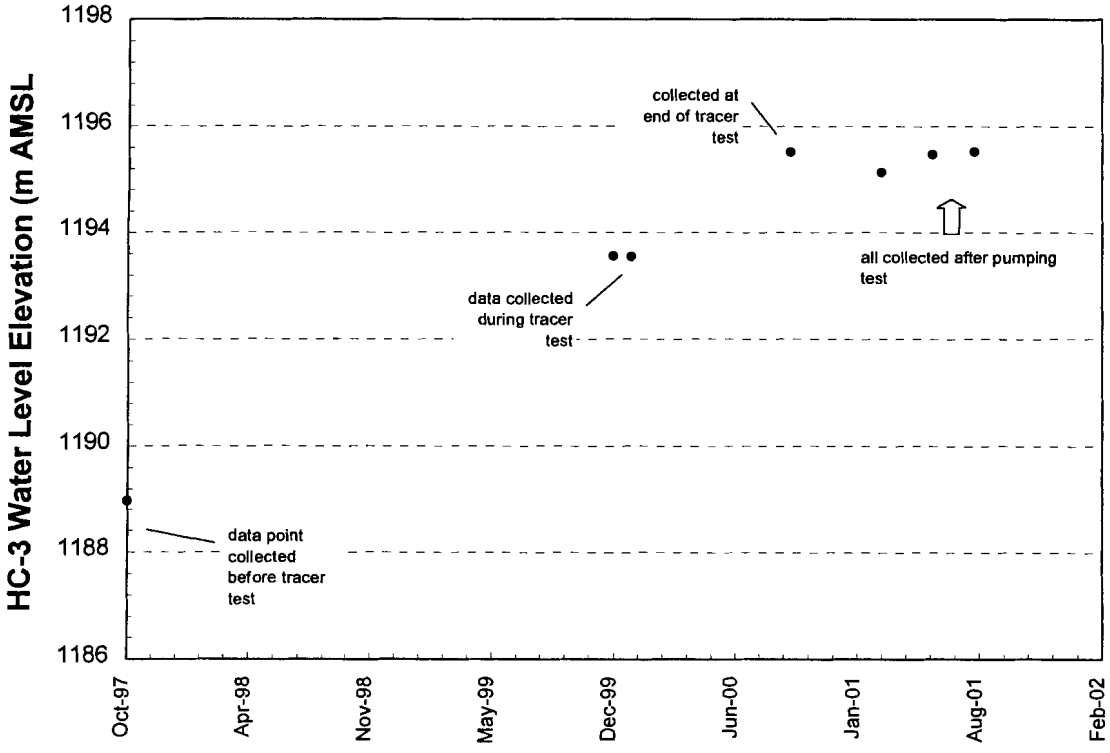

Figure 17. HC-3 water level elevations collected from November 15, 1996, to July 23, 2001.

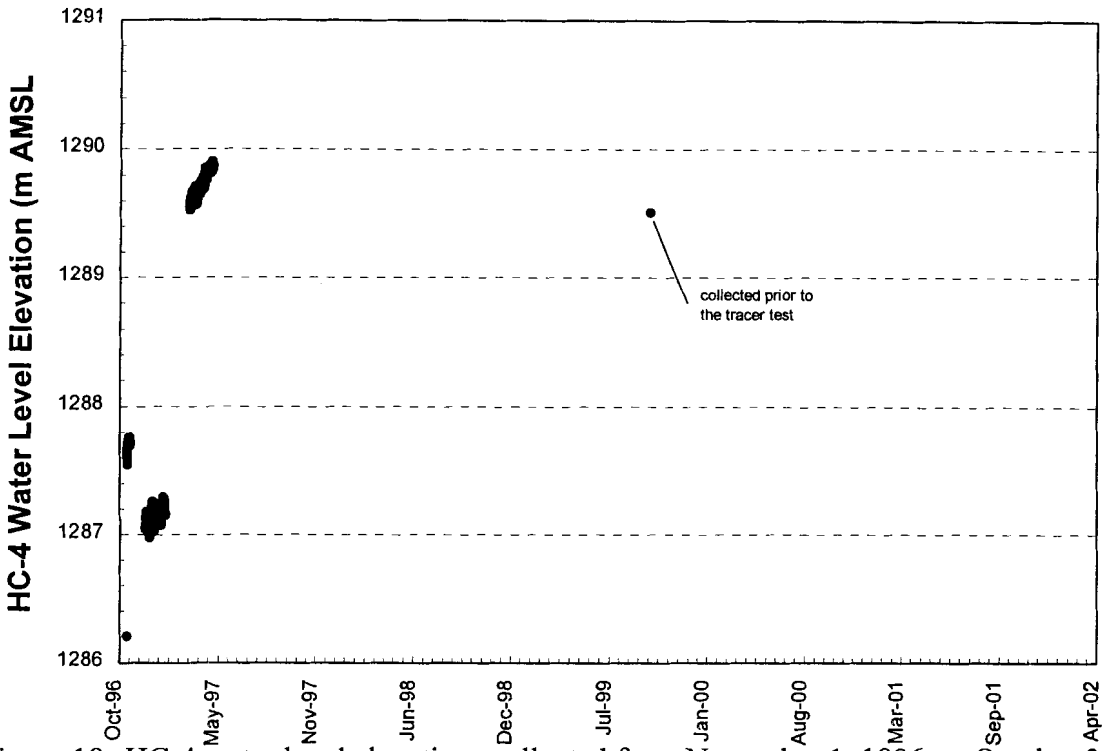

Figure 18. HC-4 water level elevations collected from November 1, 1996, to October 3, 1999.

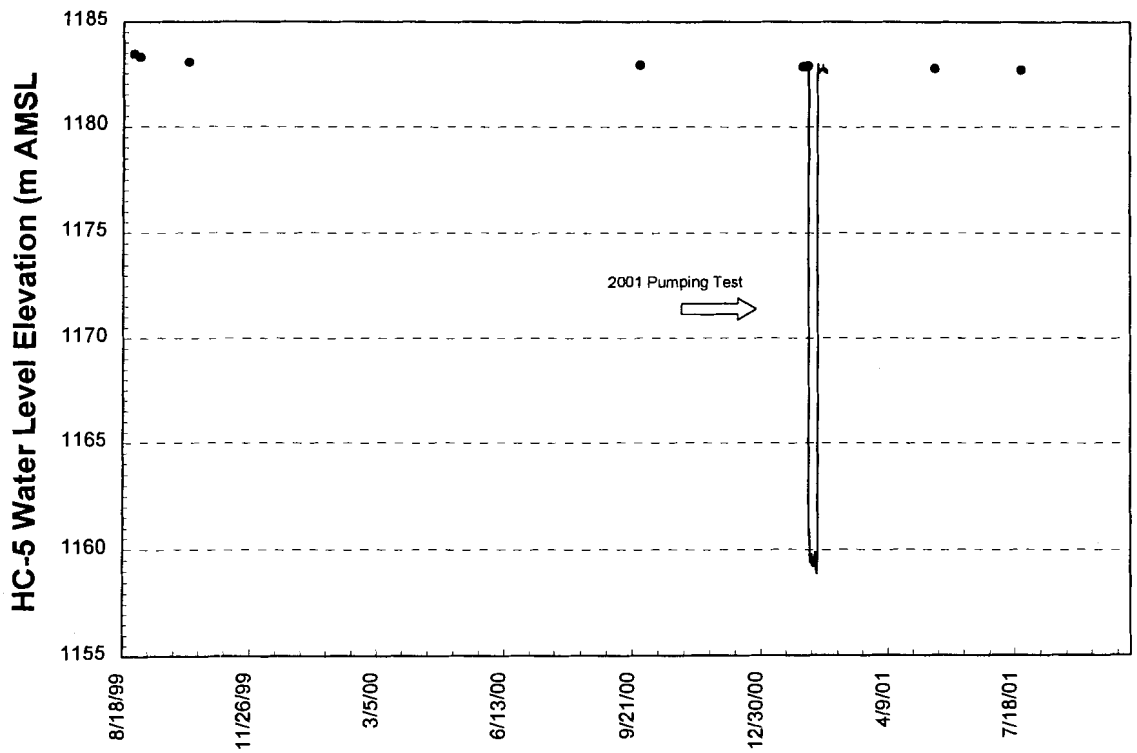

Figure 19. HC-5 water level elevations collected from August 26, 1999, to July 23, 2001.

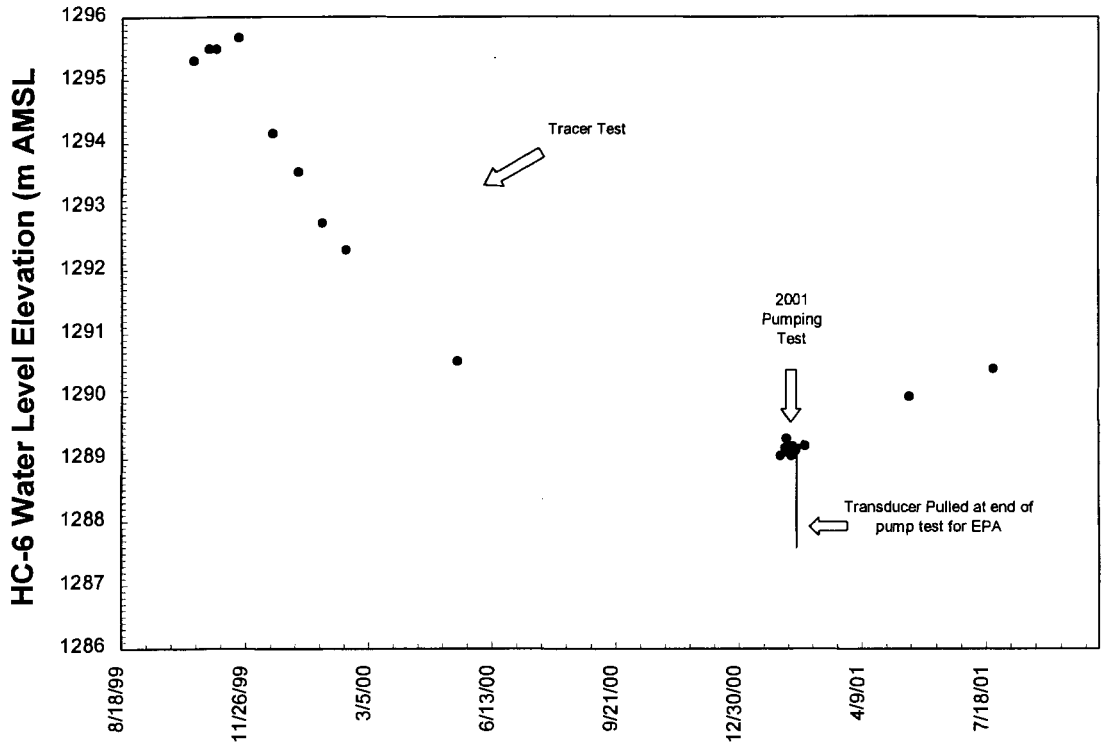

Figure 20. HC-6 water level elevations collected from October 14, 1999, to July 23, 2001.

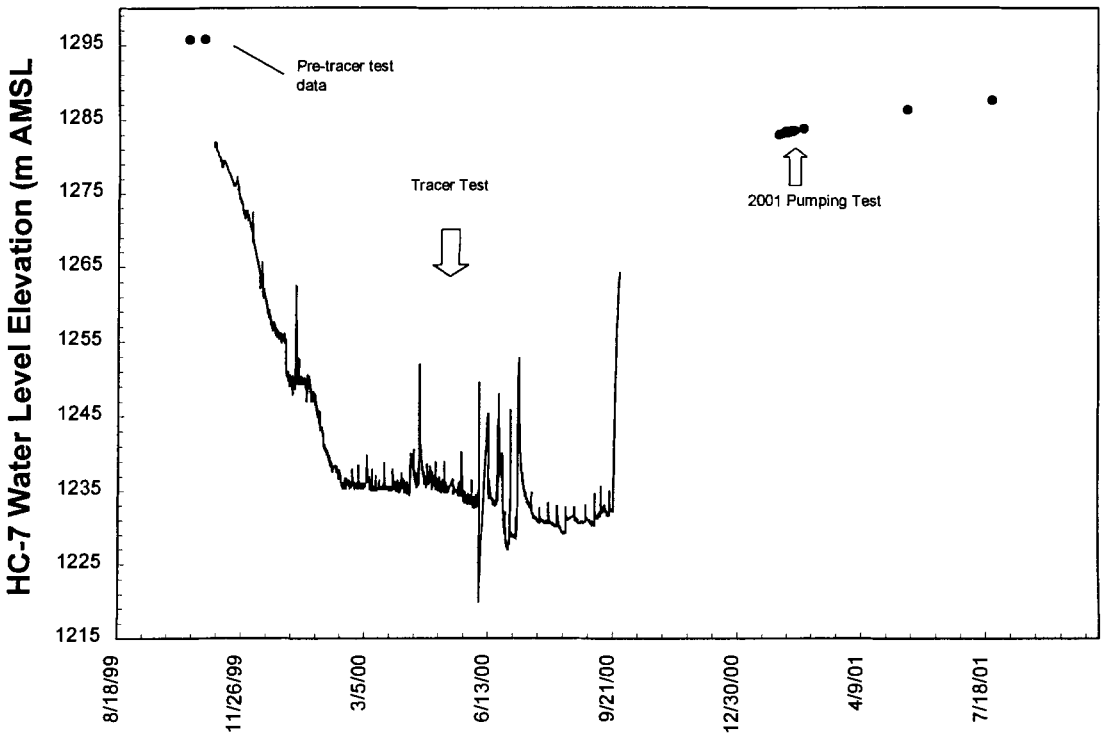

Figure 21. HC-7 water level elevations collected from October 14, 1999, to July 23, 2001.

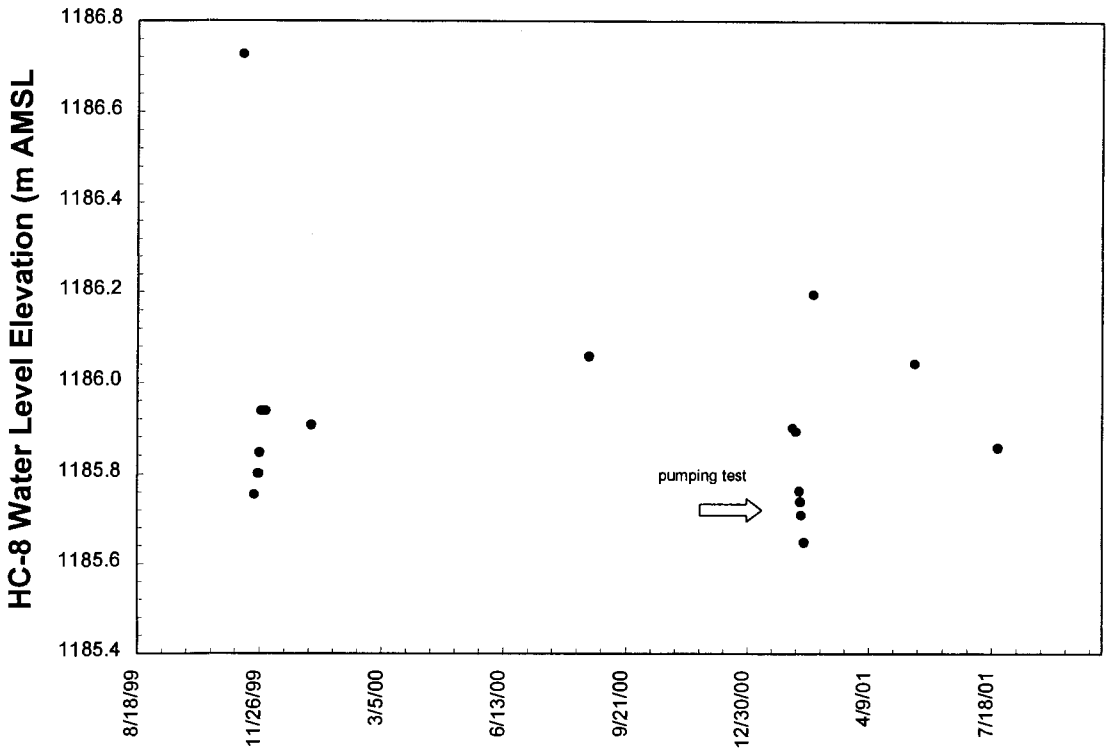

Figure 22. HC-8 water level elevations collected from November 11, 1999, to July 23, 2001.

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