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GROUND-WATER LEVEL FLUCTUATIONS IN DEVILS HOLE 1962-1999 REGIONAL STRESSES AND WATER-LEVEL CHANGES IN THE DEATH VALLEY REGION

J. R. Harrill

M. S. Bedinger

August 2005

(Originally released May 2000)

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J. R. Harrill, Hydrogeologist

M. S. Bedinger, Hydrogeologist

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WATER RESOURCES DIVISION

National Park Service - Department of the Interior
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Ground-Water Level Fluctuations in Devils Hole, 1962-1999, Regional Stresses and Water-Level Changes in the Death Valley Region

By
J. R. Harrill and M. S. Bedinger

Background

Devils Hole is a collapse depression in the limestone hills adjoining Ash Meadows Ash Meadows National Wildlife Refuge (fig. 1). The depression forms an open cavern that contains a warm water pool about 50 ft below the land surface. This pool contains a unique species of desert pupfish, ***Cyprinodon diabolis***, that is listed as endangered. The Devils Hole pupfish, less than 1 inch long, evolved from late Pleistocene ancestors left isolated in this former limestone spring when the level of the pluvial lakes of the Death Valley area receded. This population feeds and reproduces on a slightly submerged rock ledge. In 1952 a 40-acre tract of land containing Devils Hole was incorporated into the Death Valley National Monument as a detached management area. This tract is currently part of Death Valley National Park.

Devils Hole is a joint/solution/collapse opening in exposed limestone lined with travertine extending from the surface to a great depth in the Bonanza King Formation. Devils Hole responds similar to a well to hydraulic stresses on the carbonate aquifer. The location of Devils Hole in the southeastern Amargosa Desert makes it susceptible to impacts from pumping in adjacent areas. In 1967 a ranching corporation acquired large acreages in the area of Ash Meadows and developed a well field for irrigation purposes. Concomitant with expansion of the agricultural enterprise and increased pumping, the level of the Devils Hole pool began to decline (fig. 2). As the pool stage slowly declined, the submerged ledge upon which the Devils Hole pupfish feed and propagate began to be exposed to air.

There was concern that the species would become extinct because of the loss of habitat. The Federal Government began a series of actions in 1969 that ultimately resulted in a decision by the U. S. Supreme Court. The Supreme Court decision restricted pumping in Ash Meadows and established a court-mandated minimum level for Devils Hole pool of 2.7 feet below a reference washer set in the wall of Devils Hole.

After pumping was reduced in Ash Meadows, the pool level, which had declined to about 3.7 ft below the reference washer in late 1972, stabilized and then began to recover in the mid 1970's. No pumping occurred after August 1982. The water-level continued to rise until early 1988 when the average monthly level was about 1.9 ft below the reference washer. This was about 0.8 ft short of recovering fully to the 1962 average monthly levels of about 1.1 ft below the reference washer. After 1988 the pool level began to decline at a rate of about 0.04 to 0.05 ft/yr. On July 28, 1992 the decline was interrupted by effects of the Little Skull Mountain earthquake whose epicenter was located about 20 miles north of Devils Hole. The pool level responded to this earthquake by rapidly dropping about 0.5 ft and then over the next several months rising to a high of about 1.87 feet below the reference washer in June of 1993. By December 1993 it had declined back to about 2.02 feet below the reference washer and then began to decline at a rate of 0.02 to 0.03 feet per, year, which continued until about mid-1996. The trend reversed and pool levels began to rise. As of May 1999 the level was 1.95 feet below the reference washer.

The declines in the Devils Hole pool level since 1988 have raised concerns that, in the intermediate to long-term future, the pool level may fall below the court-mandated minimum level of 2.7 ft below the reference washer. Attempts to identify the causes for the change from recovering trend to declining trend have not yet isolated a single factor that can explain all the observed changes. Factors that have been considered include short-term climatic fluctuations, changes in pumping rate from wells in areas adjacent to Ash Meadows, and tectonic changes related to seismic and possibly aseismic fault creep activity.

Purpose and Scope

This report describes the water-level fluctuations in Devil Hole from 1962 to 1999. This report includes a

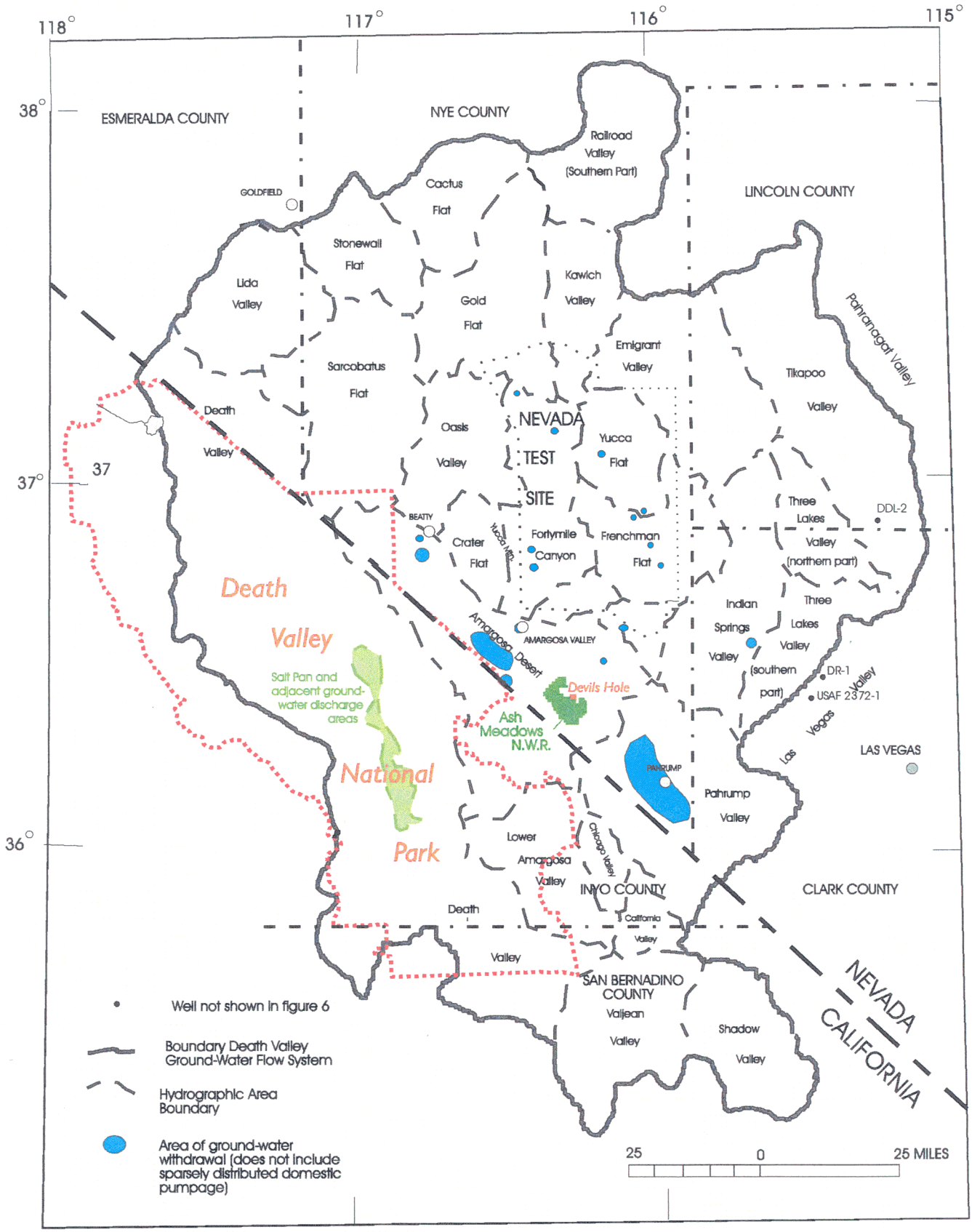

Figure 1. Location of Devils Hole, the Death Valley ground-water flow system, selected geographic features, political boundaries, and main areas of ground-water withdrawal.

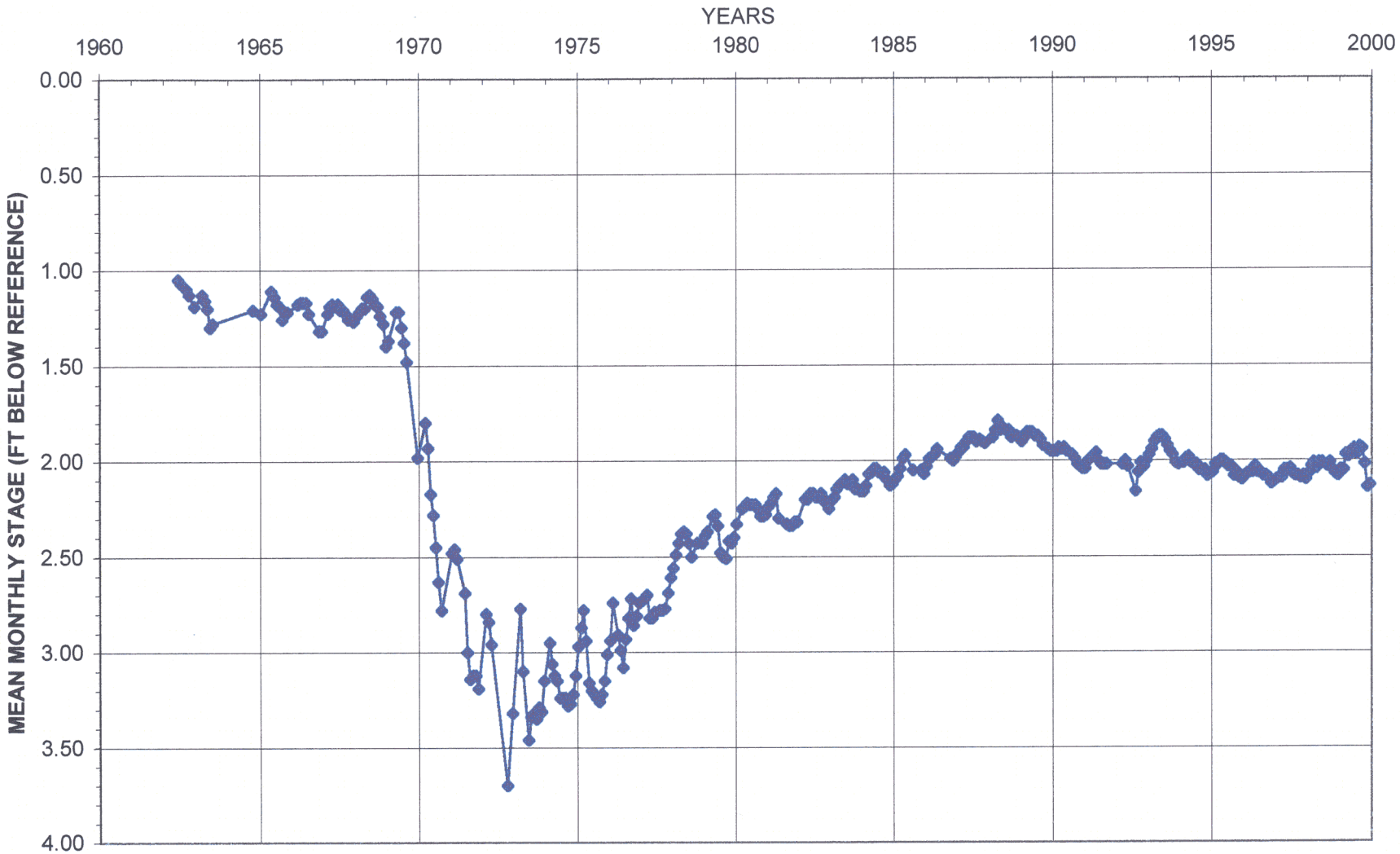

Figure 2. Stage of Devils Hole Pool 1962-1999

recent compilation of precipitation and ground-water withdrawal records for the region. Regional ground-water fluctuations are compiled and compared to the stage fluctuations of Devils Hole. The analyses of Avon and Durbin (1994) of water-level fluctuations of Devils Hole in relation to ground-water withdrawal and precipitation have been examined in view of the longer period of record now available. Projections of water-level trends in Devils Hole by Lehman and Atkins (1991), and Brown and Lehman (1993) fluctuations are compared to the longer record now available.

Short-term fluctuations in the stage of Devils hole are caused by changes in loading by earth tides and atmospheric pressure. Oscillations of water level in Devils Hole of seismic origin are common and temporary offsets of stage induced by seismic events have been identified. Identification and understanding of the effects of loading and seismicity are important in the overall interpretation of stage changes in Devils Hole. Water-level trends in Devils Hole since the 1960's are analyzed with particular reference to ground-water withdrawals and inferred recharge from precipitation. In addition, it is recognized that long-term trends and offsets of stage can be produced by tectonic, both seismic and aseismic, events. Possible tectonic related changes are pointed out, but the present report does not address such changes in detail.

Acknowledgements

The encouragement and generous assistance of William Werrell, formerly with the National Park Service, in our work at Death Valley National Park is has been very helpful and is greatly appreciated. The authors thank Randell Laczniak, Devin Galloway, Alan Burns and Aldo Vecchia of the U. S. Geological Survey for their review and helpful suggestions for improvement of the report. We thank Mel Essington and Doug Threloff of Death Valley National Park for facilitating our work in the park and providing data and information. We thank Richard LaCamera, U.S. Geological Survey, and Chris Gable and John Stark, National Park Service, for generously facilitating our acquisition of data used in the preparation of this report.

Hydrogeologic Setting of Death Valley Flow System

The Death Valley Ground-Water Flow System underlies about 15,800 mi^2 and includes about 30 ground-water basins in southern Nevada and southeastern California (fig. 1). Each basin typically contains a structural depression partly filled by material eroded from adjacent mountains. The basins are separated by intervening mountain ranges that occupy about 25% of the area. Altitude ranges from about 240 feet below sea level in Death Valley to more than 10,000 feet above sea level at several mountain peaks in the northern part of the flow system.

Annual high temperatures in Death Valley generally exceed 125° F and in other valleys in the flow system generally exceed 100° F, including Amargosa Valley where Devils Hole is located. Average annual rainfall in the flow system ranges between about 1.9 inches in Death Valley and about 4 to 5 inches in the other valleys. Areas at higher altitude have cooler temperatures and more rainfall. Above 7,000 feet annual precipitation may average between 12 to 25 inches.

Drainage is generally from mountains to adjacent basins. Some basins are topographically closed. Water accumulates in playas (intermittent lakes) following infrequent periods of high precipitation and runoff. Other basins are drained by rivers and streams that flow toward Death Valley when water is available. The Amargosa River is the most prominent of these intermittent drainages. During very wet years it flows all the way to the Death Valley Playa where a shallow intermittent lake is formed.

This area has a complex geologic history that includes several episodes of geologic deformation. The most recent episode (structural extension) is continuing at the present time. Consequently, rocks that underlie the basins and mountains are highly fractured, permitting ground water flow beneath topographic divides. The main aquifers include basin-fill aquifers, carbonate-rock aquifers, and volcanic-rock aquifers. In some localized areas ground water is also transmitted through highly fractured zones in older noncarbonate sedimentary rock. Other rocks and deposits impede ground-water flow. These include fine-grained

deposits in the basin fill, some types of volcanic rock, noncarbonate sedimentary rocks that are not highly fractured, and crystalline rocks.

Carbonate-rock aquifers are most extensive in the eastern part of the flow system and volcanic-rock aquifers are most extensive in the northwest part of the system. Consequently, flow in the eastern and northwestern parts of the flow system occurs predominantly through carbonate-rock and volcanic-rock aquifers, respectively. Some flow moves through basin-fill aquifers in all parts of the flow system.

Ground water moves from recharge areas in the higher-altitude parts of the flow system (mostly in the north) to lower-altitude valleys in the southern part of the flow system. Ground water flows down gradient along the path of least resistance, generally moving through the aquifers and around the deposits that impede flow. Some water is discharged from springs, seeps, and shallow water table areas, at intermediate areas in Oasis Valley, Ash Meadows area (adjacent to Devils Hole) and Franklin Lake. The remaining ground water flows to Death Valley, the terminus of the system, to be discharged from springs and by evaporation and transpiration from the valley floor.

Ground water that discharges from Ash Meadows is supplied by flow from 13 upgradient ground-water basins to the northeast and some subsurface inflow from Pahranagat and Las Vegas Valleys. The area that contributes flow to Ash Meadows has been described as the Ash Meadows ground-water basin (Winograd and Thordarson, 1975, p. C75). The Ash Meadows ground-water basin is a flow region included within the larger Death Valley ground-water flow system. Pahranagat Valley contributes subsurface outflow to both the Death Valley ground-water flow system and the Colorado ground-water flow system (as described by Harrill and others, 1988). The distribution of flow within Pahranagat Valley is not precisely known but most of the flow is to the Colorado ground-water flow system. Las Vegas Valley also contributes subsurface outflow to both the Death Valley ground-water flow system and the Colorado flow system. Most of the flow goes to the Colorado flow system and only the northwest part of the valley contributes flow to the Death Valley flow system.

Pool Stage Fluctuations

The record of water-level fluctuations at Devils Hole is an integration of all stresses present and past acting on the system. In response to all these stresses of various magnitudes, duration, extent and physical character, the water level at Devils Hole can react in only one of three ways: the water level can rise, fall, or remain constant. At any given time the pool level represents the net result of all the stresses that have acted on the hydrogeologic system.

The pool stage changes in Devils Hole can be separated into two basic types: 1) stage changes in response to changes in storage within the aquifer, and 2) transitory or temporary fluctuations in stage that do not represent a significant or permanent change in storage within the aquifer.

Stresses that cause changes in storage in the aquifer include changes in recharge rate to the aquifer and withdrawal from the aquifer by pumping. Such changes cause changes in storage within the aquifer and can, in turn, cause water level trends in the aquifer.

Transitory or temporary changes in ground water are caused by loading effects on the aquifer of barometric pressure and earth tides. These changes cause transitory or cyclic fluctuations that don't represent changes in storage. Earth movements caused by earthquakes commonly causes cyclic fluctuations in Devils Hole. Coseismic offsets in the water level that slowly return to near pre-earthquake level are also observed in Devils Hole and in some wells in the Death Valley region. Transitory changes, not reflecting long-term trends, often obscure the significant changes that reflect long-term changes in storage in the aquifer. Fortunately, the changes caused by tidal and barometric pressure changes can be calculated and removed from the hydrograph.

Loading and Seismic Fluctuations of Stage in Devils Hole

Earth movement caused by gravitational attraction between the earth and the moon, and to a lesser extent the sun, and changes in loading of the aquifer by barometric pressure changes cause minute changes in pore volume that are reflected in water-level change. Pore pressure changes may also reflect changes in seismic strain in the earth's crust. Earthquakes and earth tremors produced by nuclear explosions have produced water level oscillations in Devils Hole. Both distant and nearby earthquakes have caused offsets or step changes in water level in Devils Hole.

Atmospheric loading and earthtides are of a cyclic nature with components of periodicity ranging from a fraction of a day to seasonal. Loading effects of earth tides and barometric pressure changes cause small recurring changes in water level of about .1 to .3 feet overprinted on the water-level trends of Devils Hole.

Tidal Fluctuations -- Dudley and Larson (1976) describes the tidal fluctuations as having the periodicity of about 1 day causing a large diurnal change of water level. Superposed on this is a semi-diurnal change that gradually modifies the shape of the daily hydrograph. The tidal fluctuations can be seen in the trace of the Devils Hole recorder for the month of October, 1999 (fig. 3). The Hector Mine earthquake that occurred October 16, 1999 caused an offset in water level. Tidal loading produces day-to-day changes of 0.1 to 0.2 feet. The pattern of reinforcement and interference of various tidal components results in a peak daily amplitude about every week, followed by gradually diminishing amplitudes for about 1 week and then increasing during the second week to a new maximum amplitude—corresponding to the alternating "full" and "new" moon phases. The weekly maxima of daily amplitudes are generally between 0.3 ft and 0.4 feet.

Barometric Fluctuations -- Barometric pressure changes cause short term (having periodicities of one to several days) water-level changes of a much as 0.1 to 0.2 feet. Figure 4 shows the mean daily pool stages in Devils Hole for October 1999. Changes in barometric pressure loading causes a large part of the fluctuation in this hydrograph. Dudley (1976) also determined that fluctuations of water level result commonly from high winds, which cause local changes of air pressure at the pool surface. The hydrograph trace is frequently "noisy" because of winds.

We have noted that there appears to be a cyclic fluctuation of stage change, having a period of about one year, imposed on the longer-term trends. This superposed fluctuation has a high stage in the summer and low in the winter. This cycle of fluctuation is apparent in Devils Hole and in Devils Hole well, a well near Devils Hole completed in gravel deposits that overlie the Bonanza King Formation. Records of annual barometric pressure collected at a site near Beatty in the Amargosa Valley (Wood and Andraski, 1995 and Wood, 1996) also fluctuate on a yearly cycle, having the higher barometric pressures in winter and lower pressures in the summer. Figure 5 shows the mean monthly barometric pressure at the site near Beatty and mean monthly stage at Devils Hole pool for the period June 1990 through May 1992. The barometric efficiency was estimated by correlating departures of average monthly values of stage from the trend shown in figure 5 with the average monthly values for barometric pressure. The barometric efficiency of Devils Hole was determined to be about 0.31 (fig. 6). This barometric efficiency agrees with barometric efficiencies of 0.31 to 0.32 determined by Kilroy (1992, figures 5 and 6) for Devils Hole. Barometric efficiency is not constant but varies with the frequency of stress intervals. Kilroy (1992, fig 9b) estimated the barometric efficiency of Devils Hole for a frequency of 24 cycles per day to be about 0.39. Using a barometric efficiency of 0.31, the stage of Devils Hole Pool was corrected to the stage for an average barometric pressure of 34.02 feet of water. Figure 7 shows values for both the corrected and measured stages. Note that the trends for both the corrected and uncorrected stages are almost identical but that the scatter of the data points has been reduced. The R^2 value for the trends indicates that before correction, linear regression accounted for only about 44% of the variability of the data; but, after correction, linear regression accounted for about 72% of the variability of the data. The annual cycle is no longer present in the corrected data but it appears that one or more short-term cycles remain.

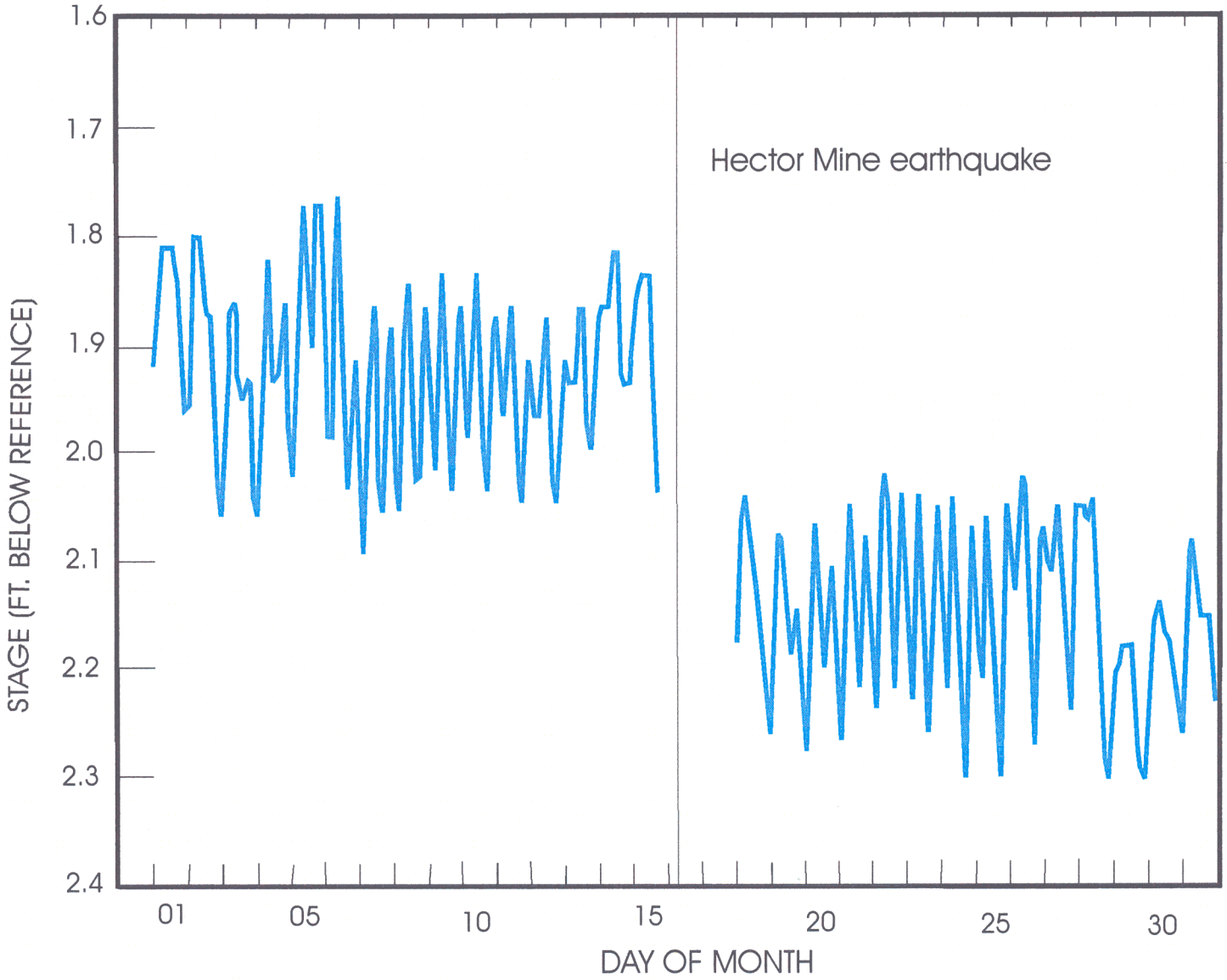

Figure 3. Recorder trace of Devils Hole pool, October 1999

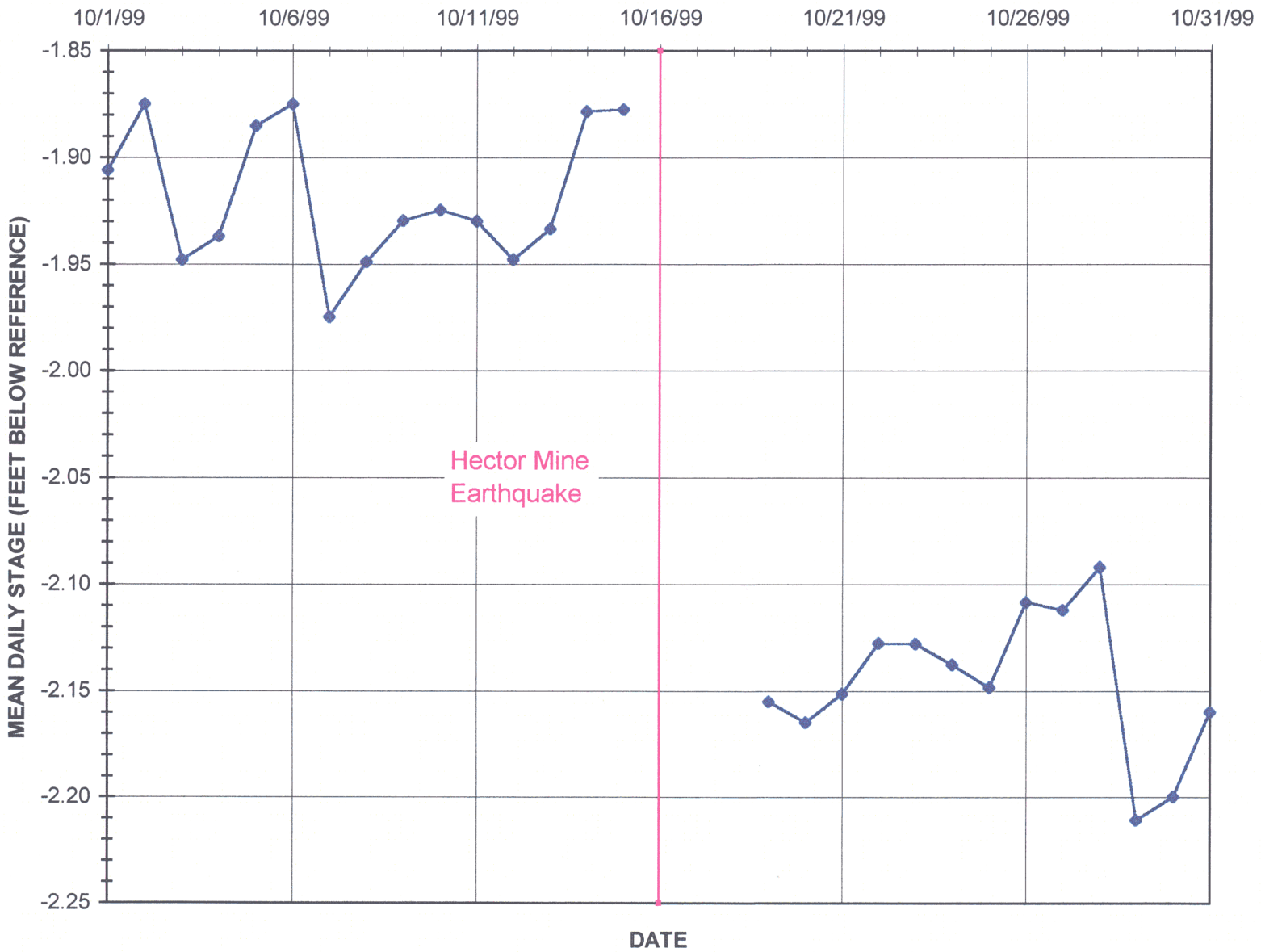

Figure 4. Mean daily stage, Devils Hole Pool, October 1999

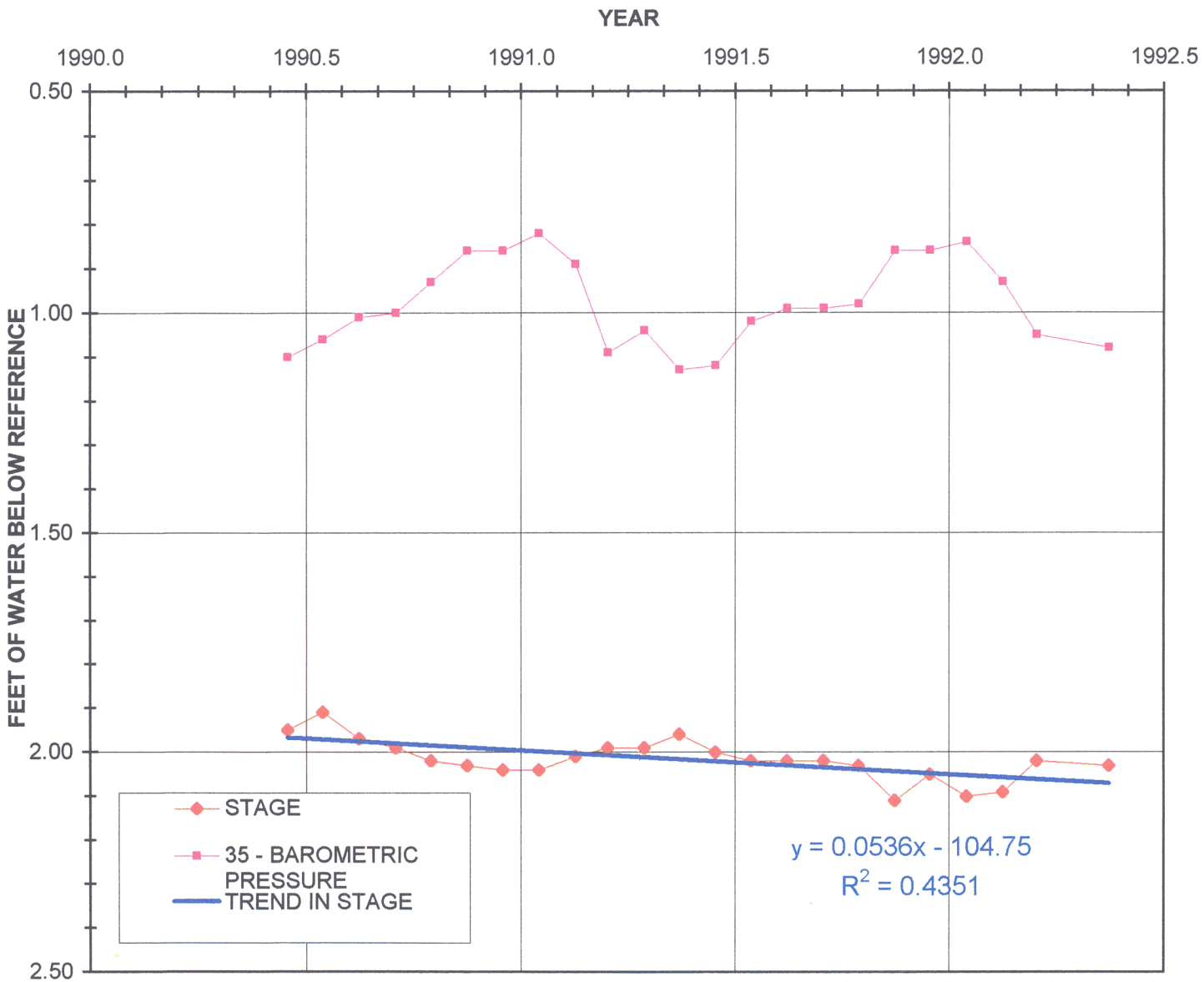

Figure 5. Mean monthly barometric pressure and stage at Devils Hole pool June 1990-May 1992

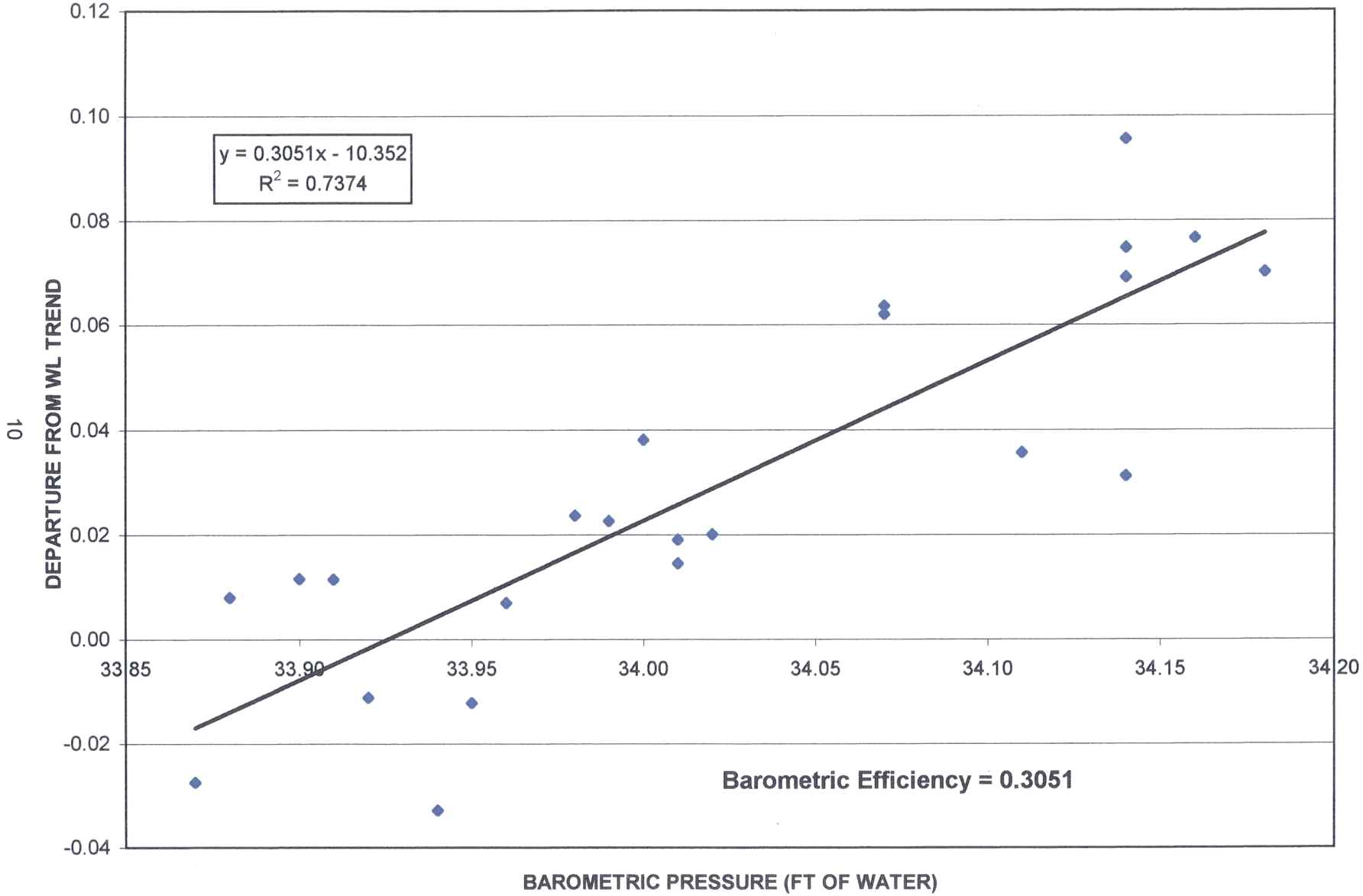

Figure 6. Relation between departure from trend in stage and barometric presssure.

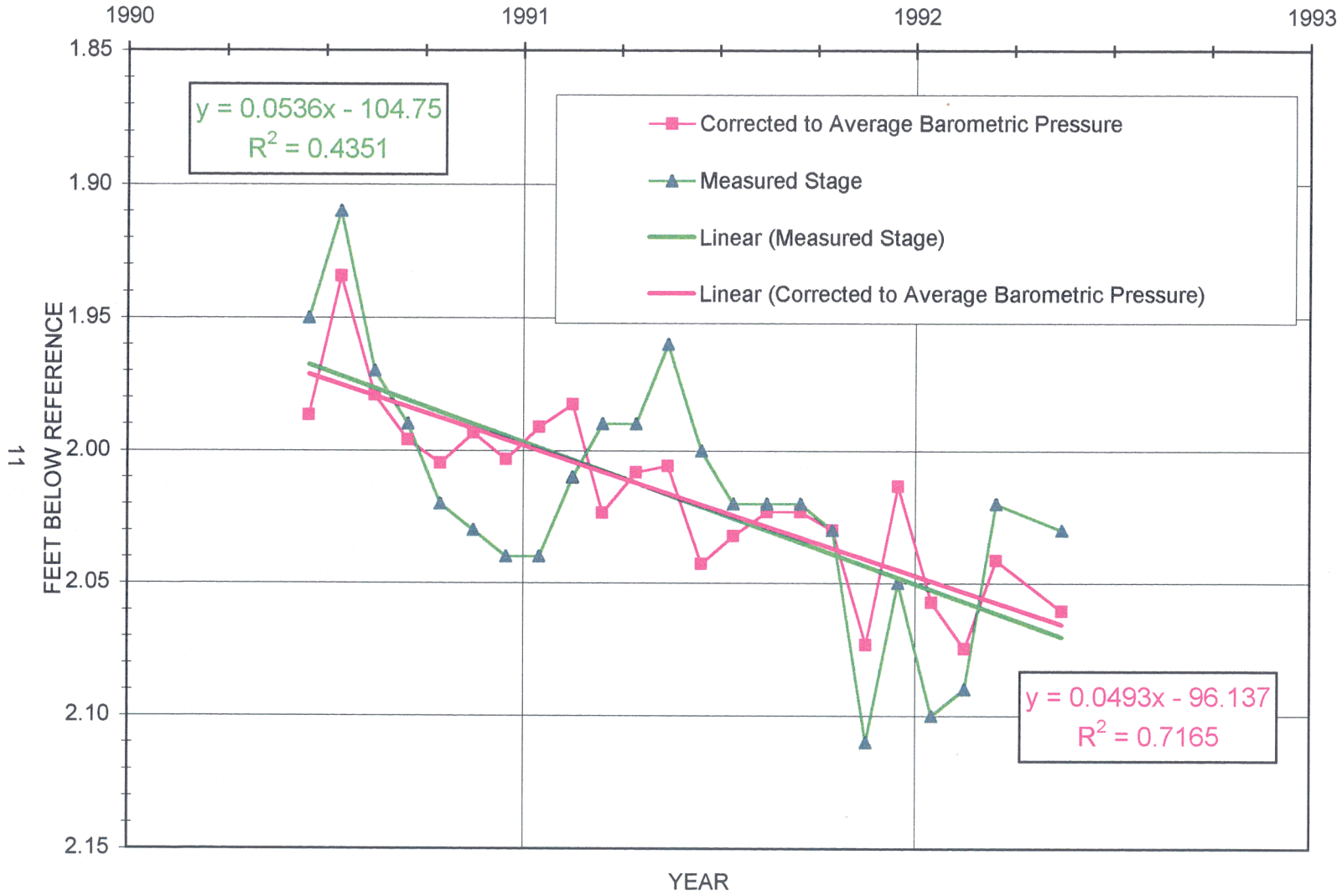

Figure 7. Devils Hole stage, measured and corrected for changes in barometric pressure

Seismic Fluctuations -- The most common seismic response of ground water is a damped oscillatory motion above and below the static water level due primarily to surface waves from distant events. Such seismic oscillations may occur in wells tapping highly transmissive aquifers (Leggette and Taylor, 1935, Cooper and others, 1965).

Dudley and Larson (1976) examined hundreds of responses of water level in Devils Hole to natural seismic events and seismic events created by nuclear explosions at the Nevada Test Site. Dudley concluded that all responses in the record he examined showed the short-term oscillations caused by ground motion. He noted the lack of permanent or long-term effect on water levels. Galloway (written communication, 1999) examined the water-level charts for Devils Hole for the period October 1962 to September 1984. During this period responses to several hundreds of seismic events, including nuclear devices at the Nevada Test Site and earthquakes, were detected in the record of water level fluctuation in Devils Hole. Galloway's records show a number of possible step changes in water level of less than .01 feet. (Apparent water-levels changes of such small magnitude could be caused by errors in the recording devices.) Of the few larger step changes, the largest was recorded to be -0.143 ft at 0630 local time on April 29, 1970. The coseismic step changes observed by Galloway are offsets of the water level observed following the oscillations caused by surface waves from an earthquake. The offset is typically not permanent; commonly the water level returns to the level of the pre-earthquake trend following the earthquake during a period that may range from minutes to days or months.

The Landers earthquake, California, on July 28, 1992 created oscillatory movement in wells in the Death Valley region. The seismic event at Little Skull Mountain north of the Amargosa Desert that followed closely on July 29, 1992 caused both oscillatory movement and coseismic water-level offsets in some wells in the region. The Little Skull Mountain earthquake produced a coseismic decline of 0.41 feet in water level in Devils Hole. Mean daily water-level values from the Stevens data logger indicate missing data for most of the period from June 16 until August 18. However the recorder functioned from July 1 to 9 and that data indicates the decline had occurred about two weeks prior to the earthquake. Intermittent measurements at the nearby Devils Hole well also indicate a response (rise) that began several weeks prior to the earthquake. The decline in Devils Hole was followed within about 90 days by recovery to near the pre-quake level. The rapid response to the pressure change in Devils Hole followed by recovery is typical of coseismic monotonic response to a pressure change produced by an earthquake.

The trace of the recorder on Devils Hole pool is shown in figure 3 for the month of October 1999. The record shows the fluctuations due to tidal and barometric pressure loading. Early in the morning (2:45 AM) on October 16, 1999, a magnitude 7.0 (Mw) earthquake occurred in the Mojave Desert, about 125 miles south of Devils Hole. Preseismic water-level fluctuations October 15 disrupted the operation of the stage recorder. Operation of the recorder was restored on October 18. The record indicates that the earthquake produced an offset of about 0.2 feet.

Water-Level Trends in Devils Hole

Trends occur when one stress (or sometimes several stresses) that cause an increase or decrease in storage becomes dominant and remains dominant over some extended period of time. By inspection of changes in stage and with information on stresses on the system we can identify with a limited degree of certainty some of the causes that produce trends in the water-level record of Devils Hole. Periods when specific stresses appear to dominate the stage in Devils Hole are shown in figure 8.

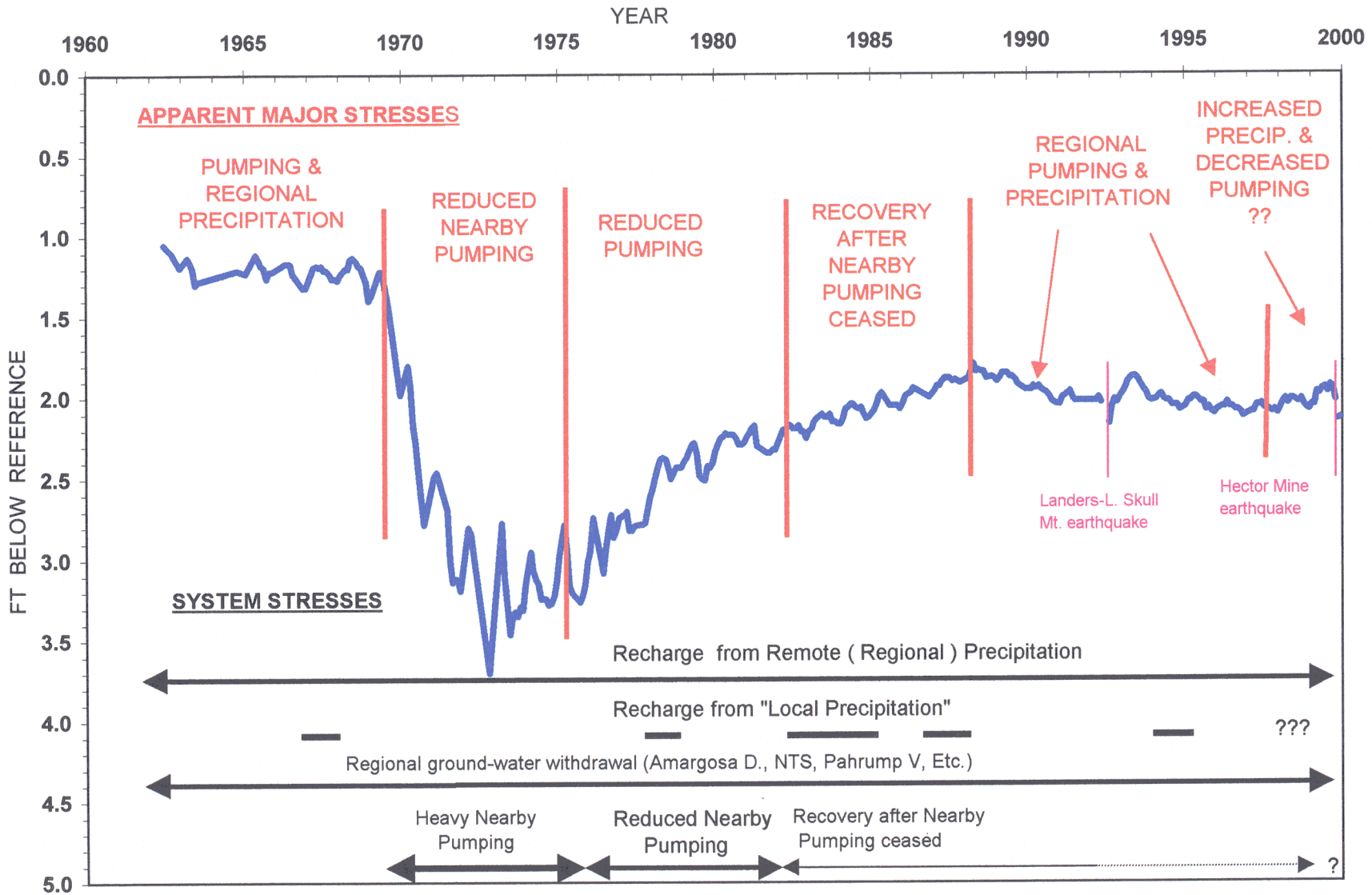

Figure 8. Factors causing change in stage of Devils Hole pool.

This illustration (fig. 8) shows a pre-local development period (1961-1969) where there is indication of a gradual decline. This could be a trend in response to regional pumping, a response to the drilling of several flowing wells in Ash Meadows (reported by Dudley and Larsen, 1976, p. 16-18), and possibly with a component related to a period of low precipitation. Regional ground-water withdrawal during this period is not known precisely. Withdrawals at the Nevada Test Site averaged about 1200 acre-feet per year, withdrawals in Pahrump Valley about 36,000 acre-feet per year, and withdrawals in the Amargosa Desert about 9000 acre-feet per year (based on 4 years of reported pumpage). Estimated discharge from flowing wells in Ash Meadows increased from about 37 acre-feet in 1962 to about 200 acre-feet in 1968. Reported values of flow totaled about 300 acre-feet for 1969 but actual flow may have been less because of the initiation of irrigation pumping.

The stage hydrograph was greatly affected during the period 1969 through 1882 by nearby pumping in Ash Meadows. Maximum pumpage occurred in 1970 through 1972 with significantly large pumping continuing through 1977. The period from 1978 to 1982 was a period of reduced nearby pumping. The nearby pumping ceased entirely in 1982. A graph of Ash Meadows pumpage is shown in figure 9. Maximum drawdown occurred in mid 1972. Water level recovery began in late 1972 although significant pumpage continued through 1977. The upward trend of water level recovery continued until 1988 when the observed rising trend ceased with the level still about 0.8 foot below 1962 levels. However, a component of recovery probably exists past the year 1988 although the small rate of change is small and masked by other factors. This statement is supported by calculations made using the Theis equation and image well theory that are presented in Appendices I and II. Appendix I contains general calculations that show, for distances remote from the pumping well, a significant portion of the drawdown will occur over a period of time much longer than the period of pumping. Appendix II contains calculations specific to pumping in Ash Meadows for the period 1962-2000. These calculations indicate that a component of recovery will continue well beyond the year 1988.

The hydrograph during the later part of the recovery period from nearby pumping was affected in 1988 and afterwards by a period of steady decline that dominated the trend from 1988 to mid-1992. The decline was interrupted in mid-1992 by rising stage following the Landers and Little Skull Mountain earthquakes. Over a period of about a year, following these seismic events, stage rose to a level about 0.25 feet above the pre-earthquake trend line. In 1994, the decline in stage resumed but at a slower rate than before the earthquakes. This decline continued until 1998. The overall declining trend from 1988 to 1998 is probably related to regional ground-water withdrawals, which had continued (fig. 15, 16, 17) since its inception before 1961. The declining trend in Devils Hole from 1989 to 1998 is similar to the declining trends in many wells in the flow system. Net changes in water level in the region from 1993 to 1999 are shown in fig. 21. The distribution and magnitude of these declines appear to suggest that the wells with declining trends are influenced by withdrawals of ground water.

In 1998 a slight recovery began which continued until October 1999. The recovery is possibly due to recharge from higher than average precipitation during several years in the earlier part of the decade. This is supported by slight water-level rises in wells DDL-2, DR-1, and USAF 2372-1 (fig 1). These wells show small rises similar to Devils Hole, however the rises started earlier. This timing is consistent for sites located upgradient from Devils Hole and closer to recharge areas. On October 16, 1999 the Hector Mine earthquake caused a decline of about 0.2 feet. Following this decline the level remained relatively stable until the end of the year 1999.

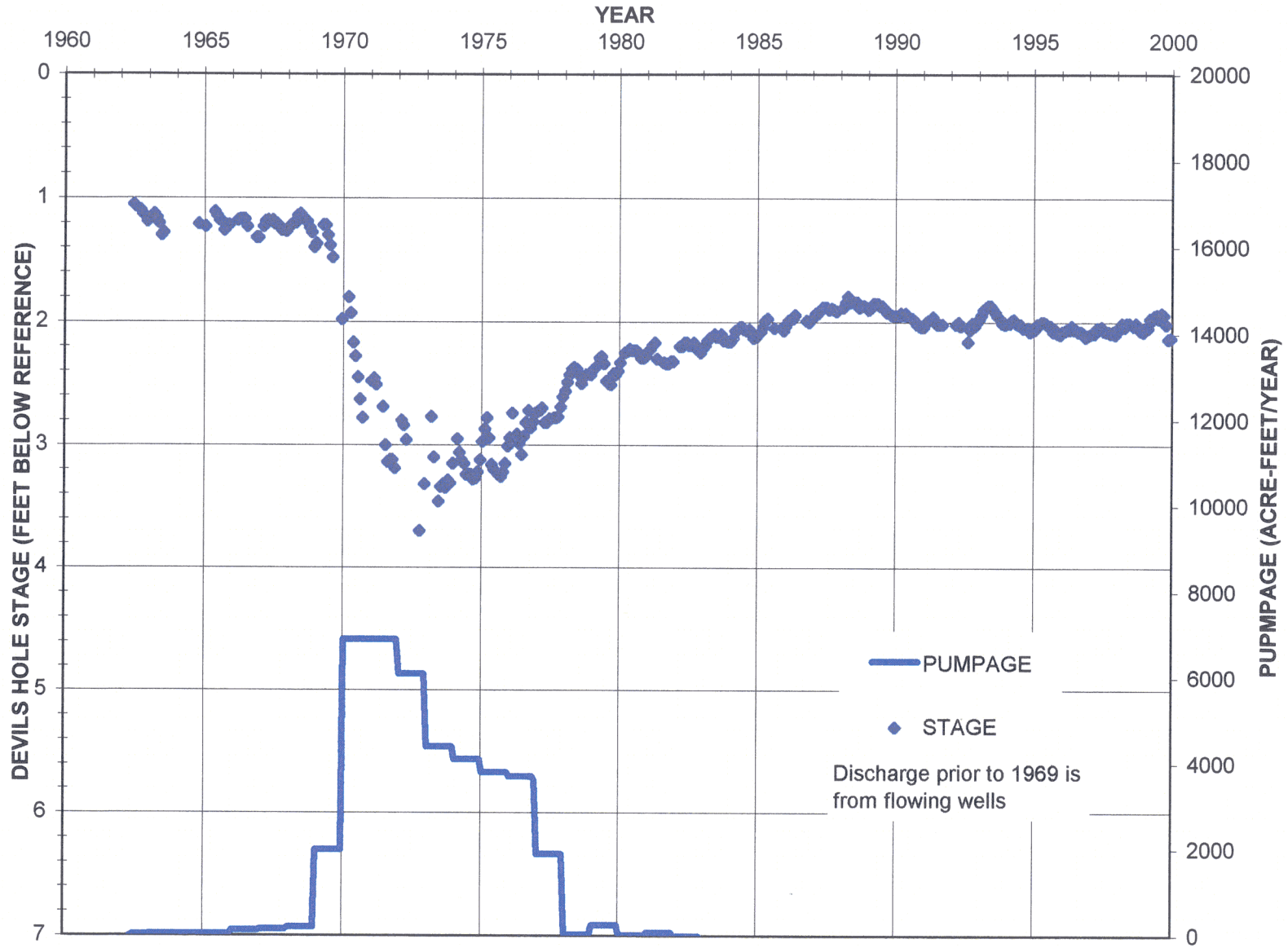

Figure 9. Annual pumpage at Ash Meadows and stage of Devils Hole pool.

Previous Studies of Stage Changes in Devils Hole

Water-level trends and cyclic changes, Lehman and Atkins (1991) and Brown and Lehman -- Water-level trends were examined statistically by Lehman and Atkins (1991) and Brown and Lehman (1993) and projections of water level in Devils Hole were made. Lehman and Atkins (1991) determined the end of the water-level recovery period by linear regression analysis of the water level in Devils Hole after cessation of nearby pumping. They considered August 30, 1989 to be end of recovery as determined by the intersection of the mathematical linear trend with the plotted water-level data. From August 30, 1989 to the end of their data, February 27, 1991, Lehman and Atkins (1991) found a linearly decreasing trend. They extrapolated this trend to find the approximate date at which water levels would fall to the court ordered level of 2.7 feet below the washer. This date was found to be June 2, 2002, which they qualified to be based on the assumption of no changes in current conditions.

Brown and Lehman (1993) analyzed the water-level trend from August 30, 1989 through July 1, 1993. This period includes the apparent response to the Landers and Little Skull Mountain earthquakes of July 1992 and part of a following upward trend of water level. Linear regressions of the record were made with and without the marked temporary lowering of water level following the earthquakes. Using the resulting linear trends, the pool level was projected to reach the mandated low water level in years 2015 and 2210, respectively. Brown and Lehman (1993) ascribe the rising trend to increased recharge because of high rates of precipitation during the winter of 1992 and spring of 1993.

Lehman and Atkins (1991) analyzed the residuals of observed water levels from the linear trend for the period from August 30, 1989 through February 27, 1991 for conformance with a cosine function; Brown and Lehman (1993) extended this analysis for the period through July 1, 1993. They found that the residuals produced a good fit with a cosine function with a period of very close to a year with a magnitude of about 0.07 feet. Lehman and Atkins (1991) concluded that the annual cycle of fluctuation represented response to the annual cycle of pumping or recharge. We present the alternative argument that the annual cycle is the direct result of the stress imposed by an annual barometric cycle (see previous section on "Barometric Fluctuations"). The annual cycle of change superposed on the stage conforms in magnitude to the change imposed by the magnitude of the annual barometric change (about 0.07 feet). The change is also in synchronization with the annual cycle of barometric change (water level low in winter, high in summer; barometric pressure high in winter, low in summer).

Brown and Lehman (1993) found a correlation between measured water level and leading two-month local precipitation from analysis of the water-level record for the period September 1, 1989 through July 1, 1993. A detailed evaluation of this conclusion was not made, however Laczniak and others (1999), maintained an extensive network of monitoring wells in the Ash Meadows area during the period 1993-97 in support of a study to measure ET. Precipitation data was also collected. They reported that "the water table shows only a minimal response to measured changes in annual precipitation" (Laczniak and others, 1999, p. 40). Only two of abut 35 sites monitored showed any significant relation between annual changes in water table and precipitation. Short-term water-table rises are coincident with precipitation but vary among wells and in magnitude (Laczniak and others, 1999, p. 47). These findings suggest that while there is a water table response to local precipitation it appears to be of relatively short duration and apparently has little effect on annual fluctuations or longer-term changes.

Regressions of Precipitation with Devils Hole Stage, Avon and Durbin (1994) -- Avon and Durbin (1994) compared observed mean stage (for climate years 1979-92) with the cumulative departure from average of precipitation indices for stations in the Spring Mountains and on Pahute Mesa. Examining the relations using various lag times of mean annual stage with precipitation, good correlations were obtained using lag times of one year for the Spring Mountains and 5 years for Pahute Mesa. The regression for the Spring Mountains data had R^2 value of 0.85; the regression for the Spring Mountains data had an r-squared value of 0.53.

Avon and Durbin (1994) also made a multiple regression between the Devils Hole stage and precipitation data from the Spring Mountains and Pahute Mesa areas. This regression had an R^2 value of 0.90

Avon and Durbin (1994) concluded that there were significant relationships between precipitation in the Spring Mountains, Pahute Mesa and stage in Devils Hole. They further concluded that precipitation trends are the most likely explanation for the decline in stage at Devils Hole observed since 1988.

We have examined the regression relationships between precipitation and stage developed by Avon and Durbin (1994) by two methods. The first method was to use the Avon and Durbin regression to extend the calculation of stage to the present time (1999). This provides a comparison of the measured stage with the calculated stage for an additional seven years. The second method was to use the Avon and Durbin regression to project backward in time and compare the computed with observed stages before the episode of local pumping began.

Precipitation data for the years 1965 to 1979 and 1992 to 1997 in the Spring Mountains were obtained from the State Engineers Office. Similar years of data for Pahute Mesa were obtained from the Desert Research Institute. The Desert Research Institute has maintained a precipitation database for the Department of Energy for a number of years. These data were used to extend the results using the regression equations developed by Avon and Durbin (1994) to climate year 1997. Precipitation data for the Spring Mountains are listed in Appendix III and precipitation data for Pahute Mesa are listed in Appendix IV. Avon and Durbin (1994) developed precipitation indices for the Spring Mountains by averaging the precipitation data from 6 sites and for Pahute Mesa by averaging the precipitation data for two sites. The precipitation indices for both areas were extended through climate year 1997 and the indices for the Spring Mountains and Pahute Mesa are shown in figures 10 and 11, respectively.

Figure 12 shows observed stage for Devils Hole and calculated stage using the Avon and Durbin (1994) regression based on the Spring Mountains data. Cumulative departure from precipitation is also included in the illustration. During the calibration period (1979-92) of Avon and Durbin (1994), there is very good agreement between the observed and calculated water levels. However, starting in 1992 the calculated stage begins to deviate from the observed water level. Then, the calculated level rises while the observed water level declines. Projecting back toward 1962 the regression calculates a stage well below the measured stage before nearby pumping began.

Figure 13 shows calculated and observed stage for Devils Hole based on Pahute Mesa data. There is relatively good agreement between the observed and calculated water levels during the calibration period (1979-1992). After 1992 the calculated water levels depart from the observed levels. The computed stage declines but the amount of decline is over-estimated by the regression equation. Projecting backward to 1969 the projected stage in 1969 is well below the measured pre-local pumping water levels.

Figure 14 shows the observed and calculated stage at Devils hole using the multiple regression equation of Avon and Durbin between stage and precipitation at Spring Mountains and Pahute Mesa. The agreement between observed and calculated values during the calibration period (1979-1992) is very good with an R^2 value of about 0.9. However, as with the simple linear regressions with Spring Mountains and Pahute Mesa, starting in 1992 the calculated values depart from the observed values. Also, the backward projected stages to pre-local pumping levels are well below the measured stages.

These differences suggest that the relation between precipitation and water level in Devils Hole for the period 1979-1992 represents a good correlation but does not represent a cause-effect relationship. Factors other than precipitation probably were influencing the water level during the calibration period.

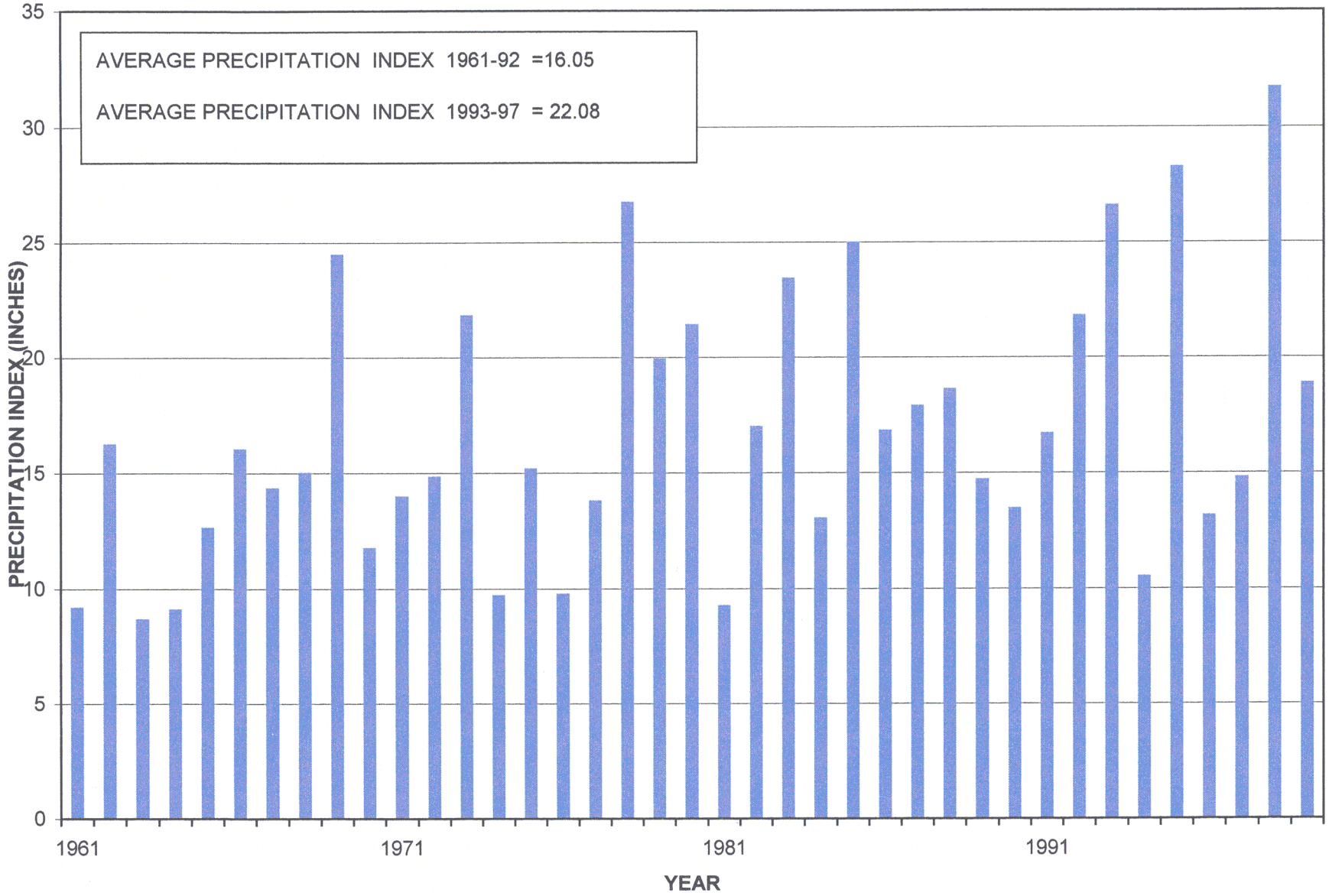

Figure 10. -- Spring Mountains precipitation index 1961-99

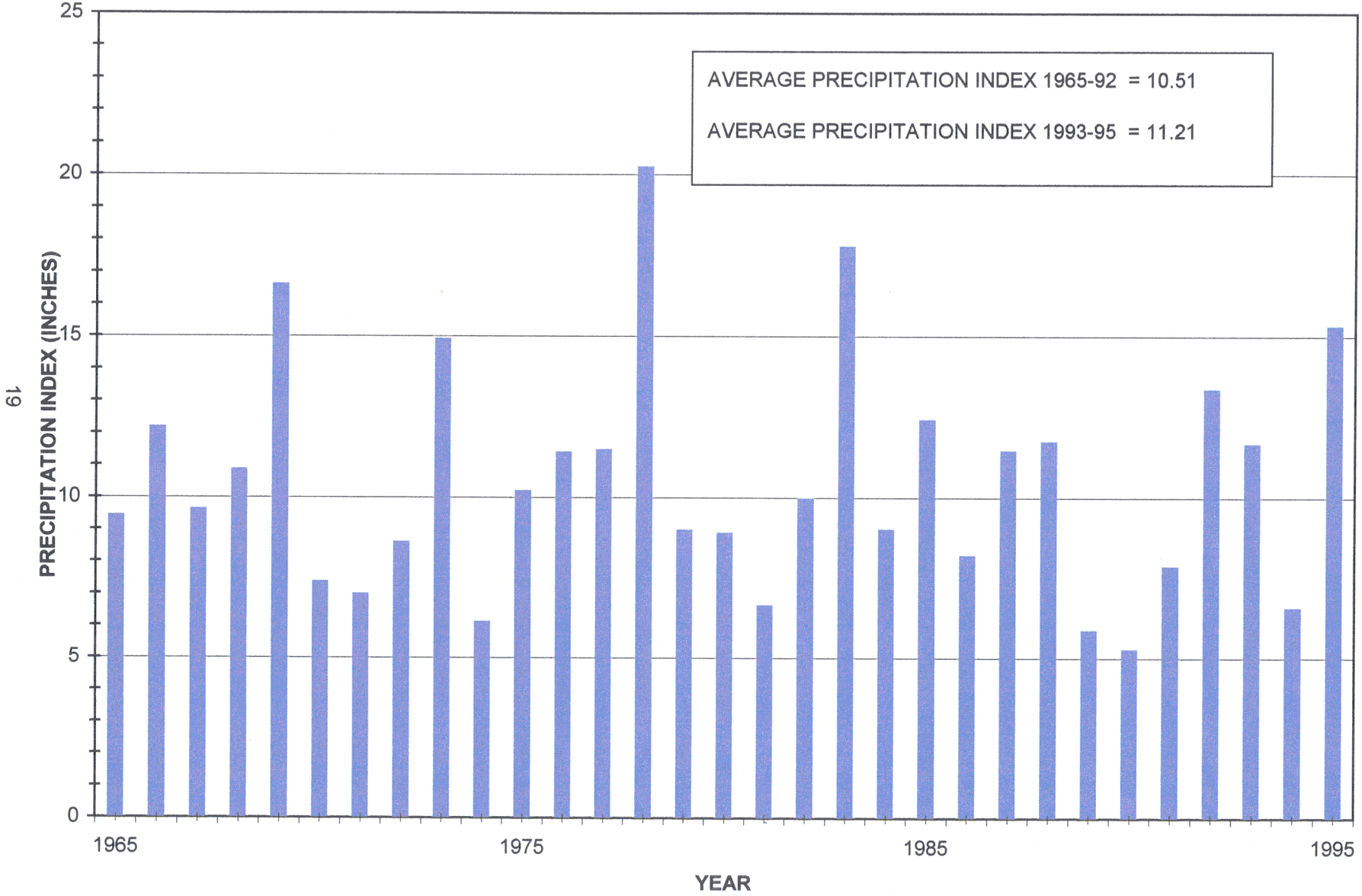

Figure 11. -- Pahute Mesa precipitation index 1965-95

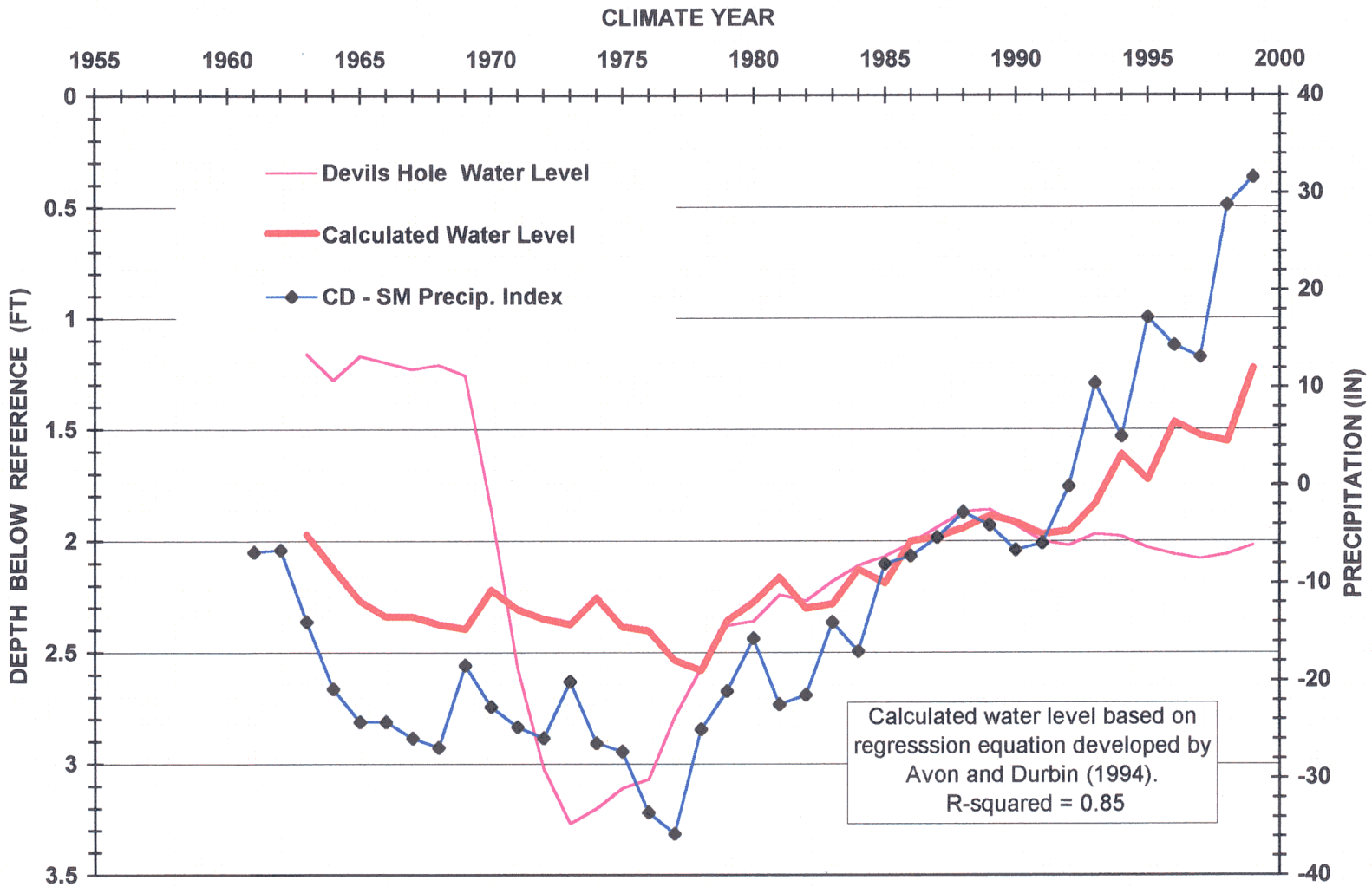

Figure 12. -- Observed and calculated stage of Devils Hole and cumulative departure from Spring Mountains Precipitation Index

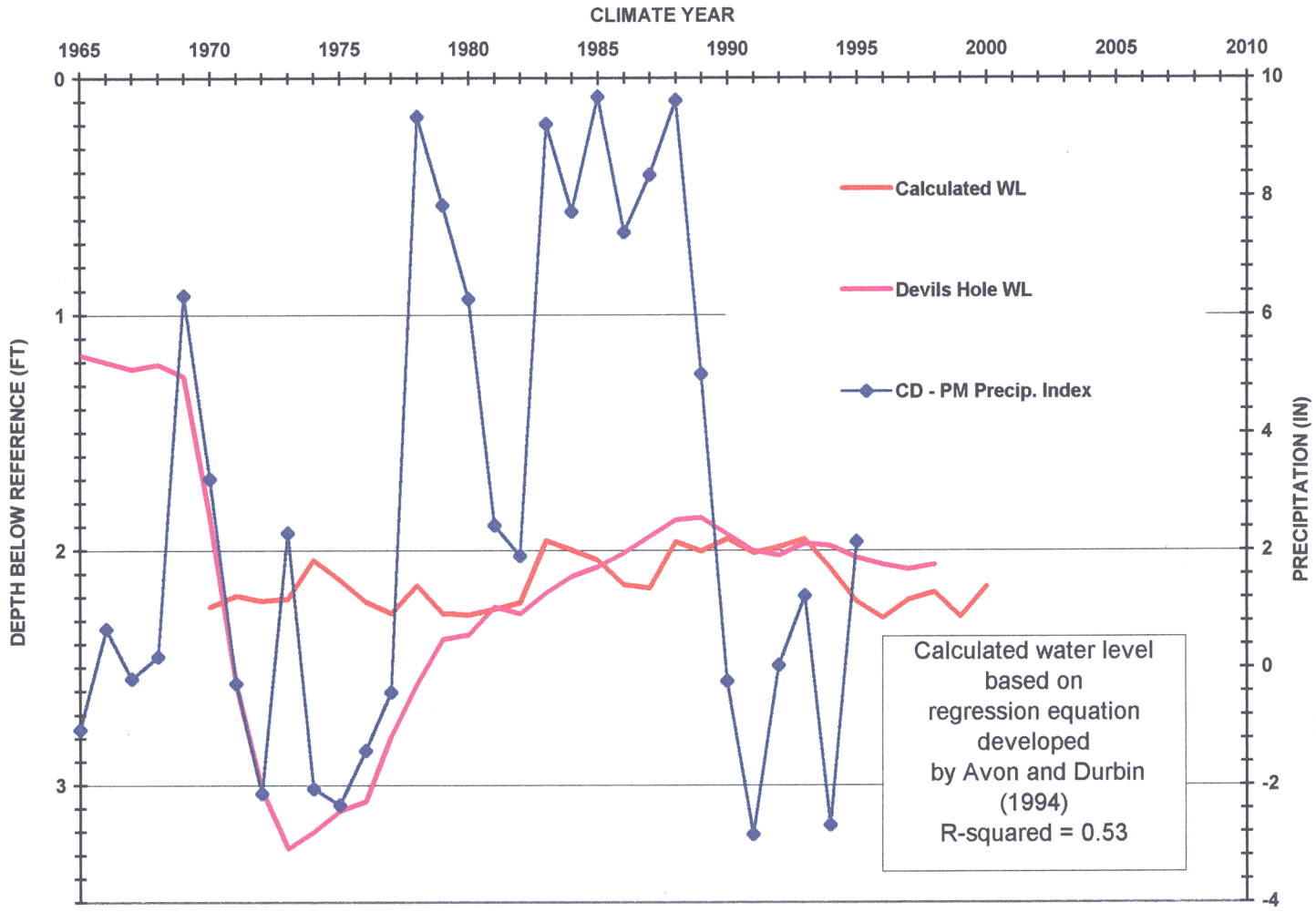

Figure 13. -- Observed and calculated stage of Devils Hole and cumulative departure from Pahute Mesa Precipitation Index.

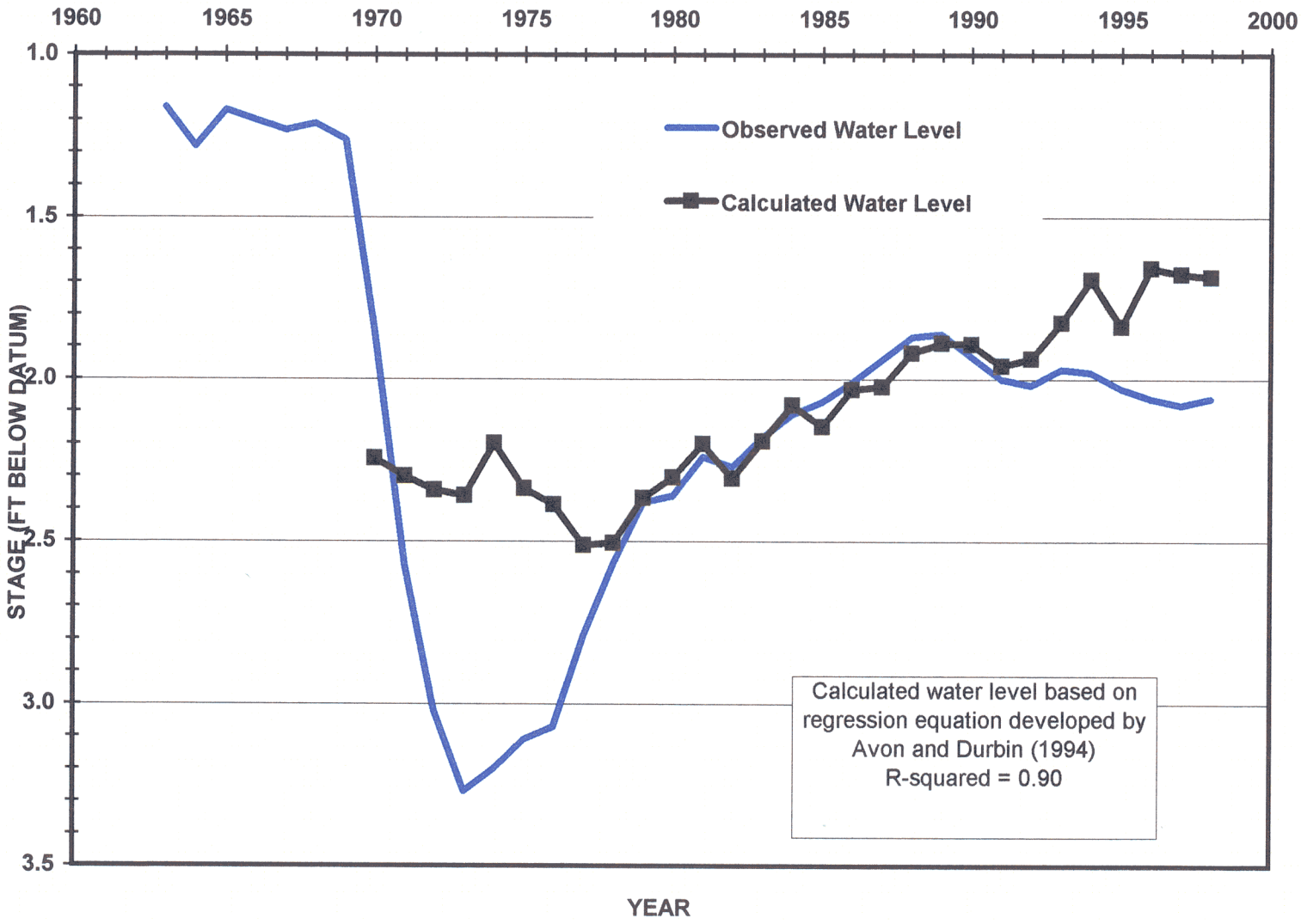

Figure 14. Observed and calculated water level at Devils Hole using multiple regression.

Evaluation of the Avon and Durbin (1994) Regressions of Stage with Precipitation -- The analysis of Avon and Durbin fails to project accurate stages for Devil Hole forward or backward beyond the period of regression analysis. The most obvious reason no significant long-term regression relationships were found is that the stage of Devils Hole during much of the period of analysis was recovering from the period of nearby local pumping. Heavy nearby pumping occurred from 1969 through 1975. Reduced local pumping occurred from 1976 through 1982. The period analyzed by Avon and Durbin was thus greatly affected by recovery from the nearby pumping.

The hydrograph of Devils Hole stage (fig. 2) shows a long term declining trend from the period 1962 through 1969 and becoming dominant one again during the later phases of recovery from local pumping. Projecting the stage backward using the regression of Avon and Durbin shows an offset in stage that is not accounted for by the regression of Avon and Durbin. Avon and Durbin attribute the offset to a "more or less permanent dewatering of the valley–fill aquifer due to intensive pumping". Pumping had not caused a permanent dewatering of the aquifer; rather, the regression of Avon and Durbin was made during the period the stage was recovering from nearby pumping.

Avon and Durbin determined different regression relations between precipitation and stage for the two periods, 1962-1969 and 1979-1992, before and after the period of nearby local pumping. Avon and Durbin propose that the relation before nearby pumping reflects damping of stage fluctuations in the confined carbonate aquifer by greater evapotranspiration for the water table prior to local pumping. Avon and Durbin are referring apparently to an assumed more stable head in the water table aquifer affecting the fluctuations of head in an underlying confined aquifer. However, head changes between the artesian and water-table aquifer would be greatly attenuated by the confining beds above the confined aquifer. In addition, there are no data to confirm that the water level in the water-table aquifer was significantly affected by pumping. Irrigation water was spread on fields and this would tend to maintain the water table at shallow depth. The flow of large springs from the confined aquifer in the Ash Meadows area probably produces the greatest damping effect on fluctuation in the confined aquifer. The springs continued to flow before, during and after the local pumping episode. Their damping effect would be similar before, during and after the local pumping episode.

We believe the offset in water level between pre-1969 and post-1988 is due in part to a long-term declining trend that continued during the period of nearby pumping and in part to a sustained period of recovery that was incomplete as of 1988 (see Appendix II).

Finally, we raise the issue that simple regression analysis is a method not well suited to evaluate the relation between precipitation and stage of Devils Hole pool. Devils Hole is located near the terminus of the Ash Meadows flow system, which is a regional-scale system that contains multiple recharge areas. The precipitation on each of the recharge areas will differ. The time required for precipitation to infiltrate down to the water table and become recharge would differ, not only between each recharge area but also between the several hydrogeologic environments likely to be present at each recharge area. Moreover, the recharge areas are at different distances from Devils Hole. Consequently, recharge from each area, or pressure changes associated with pulses of recharge, will have a different lag time before arriving at Devils Hole. These factors are all integrated into a single stage level at Devils Hole pool. A major problem with simple linear regression is that the factors just mentioned cannot readily be integrated into a single variable suitable for regression against the pool level.

Analysis of Effects of Regional Ground-Water Withdrawal, Avon and Durbin (1994) -- Avon and Durbin (1994) attempted to examine the relation between cumulative pumpage and stage by linear regression. They argue that cumulative pumpage is the appropriate independent variable to use in the regression rather than annual pumpage. They point out that if annual pumpage were to remain constant from year to year, causing a gradual stage decline, linear regression would indicate no relationship between pumpage and stage.

Annual pumpage for Amargosa Valley was available to Avon and Durbin for six years, 1985-1989 and 1991. Linear regressions were performed using zero and one-year lagging average annual stage. They report the zero-year lag returned no significant relationship and the one-year lag returned a negative, physically

implausible,relationship.

Annual pumpage for Pahrump Valley was available for the periods 1963-1968, 1983-1989 and 1991. Seven regression analyses were attempted using various periods, combinations of periods and with various lag times for stage, ranging from zero to three years. Each of the seven regressions performed was determined to be either not significant and/or not physically plausible.

Avon and Durbin did not attempt to determine a regression relation between pumpage at the Nevada Test Site and Devils Hole.

Evaluation of Avon and Durbin (1994) Analysis of Effects of Withdrawal -- The Avon and Durbin analysis of effect of pumping on Devils Hole stage is hampered by several factors: First, the pumpage data were for relatively short periods and the periods were effectively reduced in the regressions that used lag periods. Second, the statistical model does not well represent the physics of the system. The effect of pumping is a long-term response and though the response may be heavily weighted in one year, the response is distributed over a long period of time, usually several years. The statistical model, making the dependent variable a function of cumulative pumpage, can not account for a rise in water level in response to a decrease in pumping. Moreover, cumulating pumpage creates a variable with a strong linear trend that will correlate well with any other variable that exhibits a trend. Third, the analysis period was greatly affected by recovery from nearby Ash Meadows pumping which had recently ceased. Avon and Durbin (1994) were attempting to establish a regression relation between distant pumping and stage during a period when the stage was influenced by recovery from cessation of nearby pumping.

Historic Pumpage in the Death Valley Region

We have compiled pumpage data for the Amargosa Desert through 1998, Pahrump Valley through 1998, and the Nevada Test Site through 1999. These data are listed in Appendix V. Pumping in Amargosa Valley is centered in the Amargosa Farms area, about 15 miles northeast of Devils Hole; the nearest production well to Devils Hole is about five miles. The Amargosa Farms area is in the same hydrologic basin as Devils Hole. The maximum historical decline of ground-water levels in the area of heavy pumping probably has exceeded 40 feet. An additional pumping center is present in the northwest part of the valley several miles south of Beatty. Water is being withdrawn from this area for mining purpose. Annual pumpage in the Amargosa Desert is shown in figure 15. The general location of this pumping is shown on figure 1.

Pahrump Valley is an adjacent valley east of the Amargosa Desert. The maximum historical decline of ground-water levels in the area of heavy pumping exceeded 100 feet in 1976 (Harrill, 1986). Ground-water discharge from Pahrump Valley is believed to occur largely to the southwest through carbonate rocks underlying the Nopah Range to Chicago Valley and California Valley (Harrill and others, 1988). However, a hydraulic head difference of about 200 feet exists from Pahrump Valley to the carbonate aquifer at Devils Hole. Winograd and Thordarson (1975) review the hydrogeologic and geochemical evidence that mitigate against a significant rate of ground-water movement from Pahrump Valley to Ash Meadows. The record of annual pumpage in PahrumpValley is shown in figure 16. The general location of this pumping is shown on figure 1.

Pumping at the Nevada Test Site and an adjacent area that includes the Yucca Mountain Project, is from about 22 wells in five basins (Yucca Flat, Frenchman Flat, Mercury Valley, Jackass Flat, and Buckboard Mesa). The well locations range from about 18 to 60 miles north of Devils Hole. The study of the hydrogeologic flow system by Winograd and Thordarson (1975) indicates that ground water flow from the eastern part of the Nevada Test Site is in the Ash Meadows ground-water basin (as is Devils Hole) which is a sub-flow system of the Death Valley flow system. Ground-water flow from the western part of the Nevada Test Site in the Pahute Mesa-Alkali Flat-Furnace Creek sub flow system of the Death Valley flow system. Although ground water from the western part of the Nevada Test Site does not flow directly to Devils Hole, there is no hydrogeologic data that would indicate hydraulic stress would not be transmitted from one sub-flow system to the other. The record of pumpage at the Nevada Test Site is shown in figure 17. The general location of this pumping is shown in figure 1.

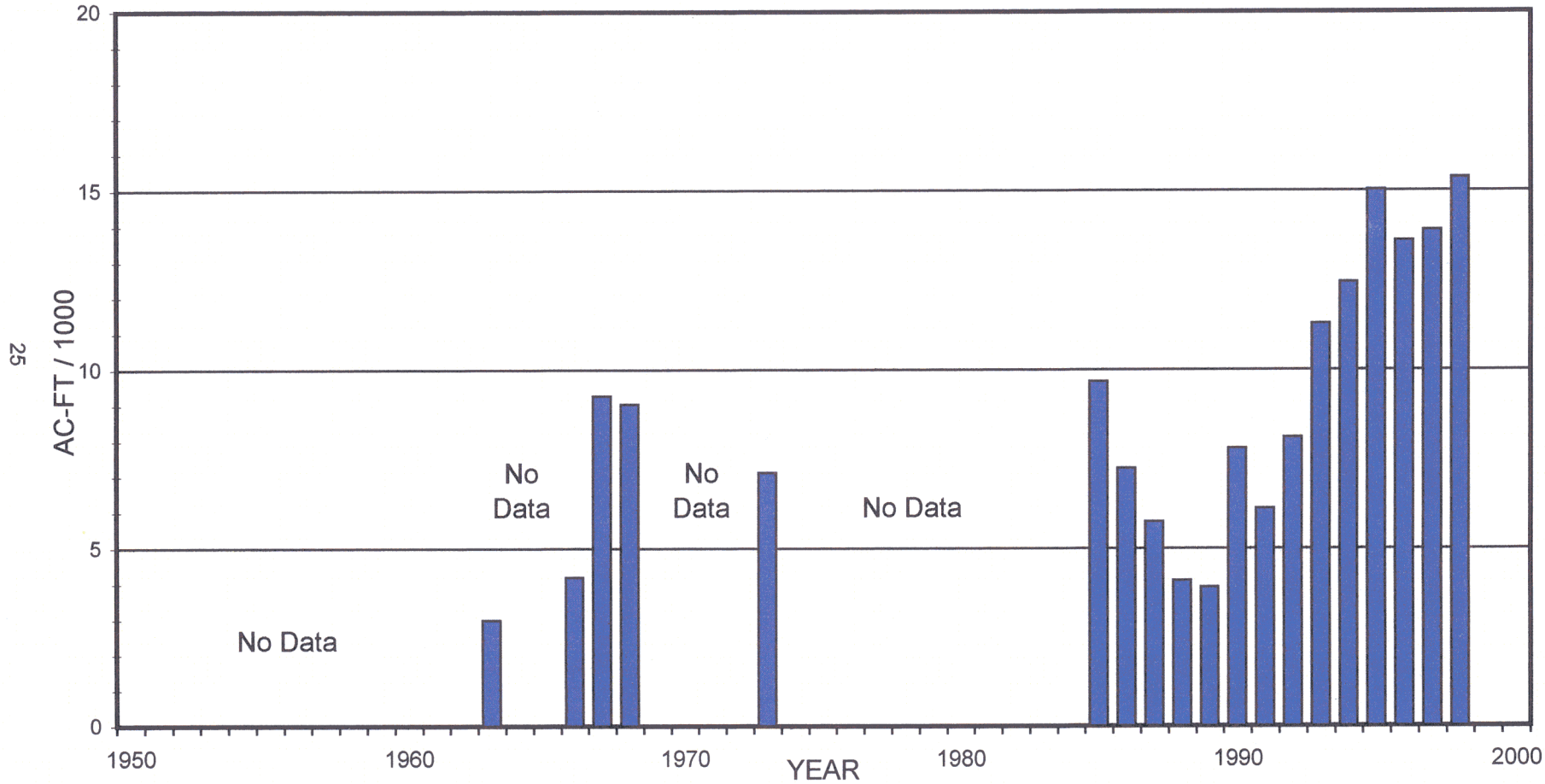

Figure 15 Historical pumpage from the Amargosa Desert

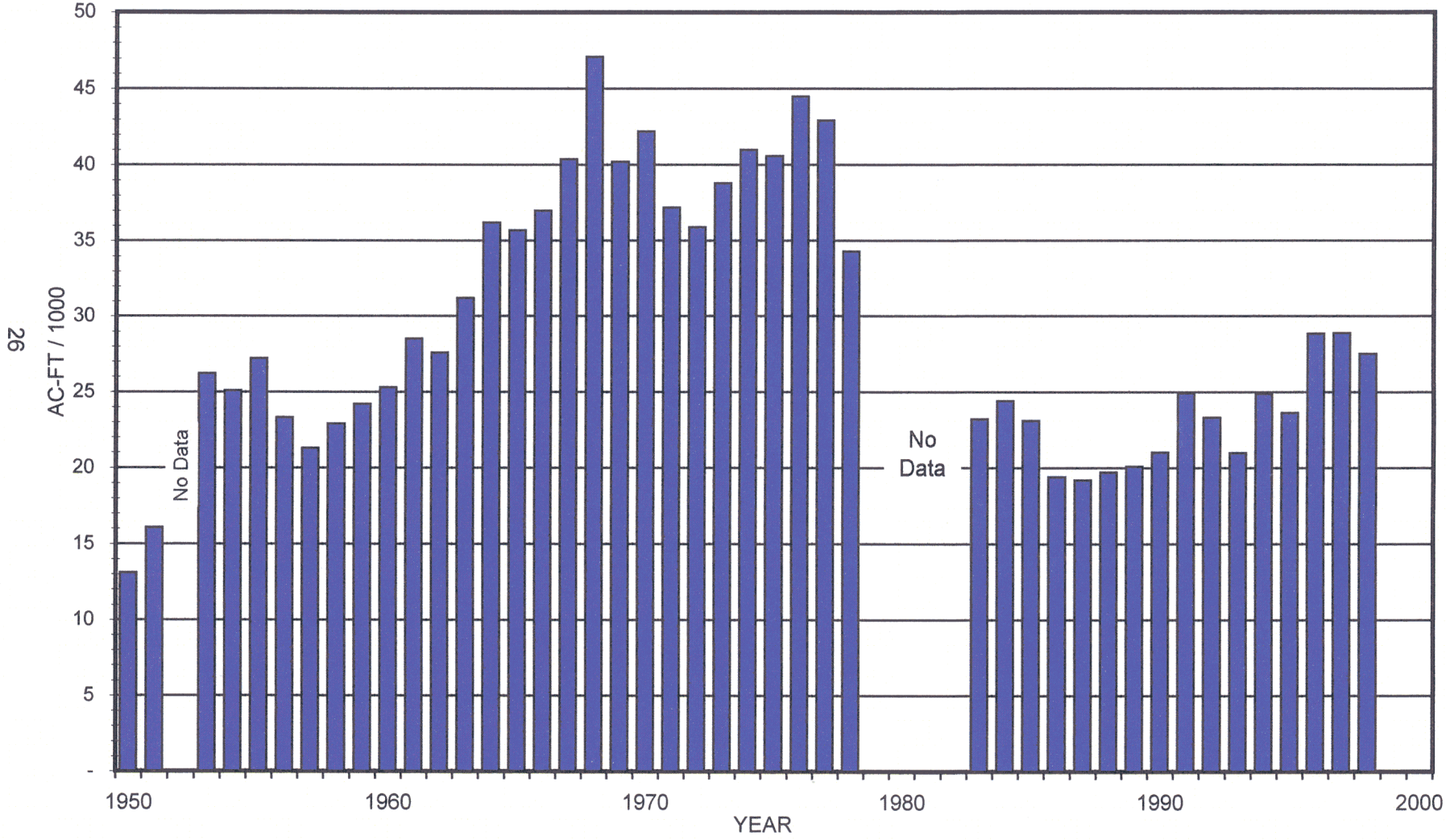

Figure 16 Historical pumpage from Pahrump Valley

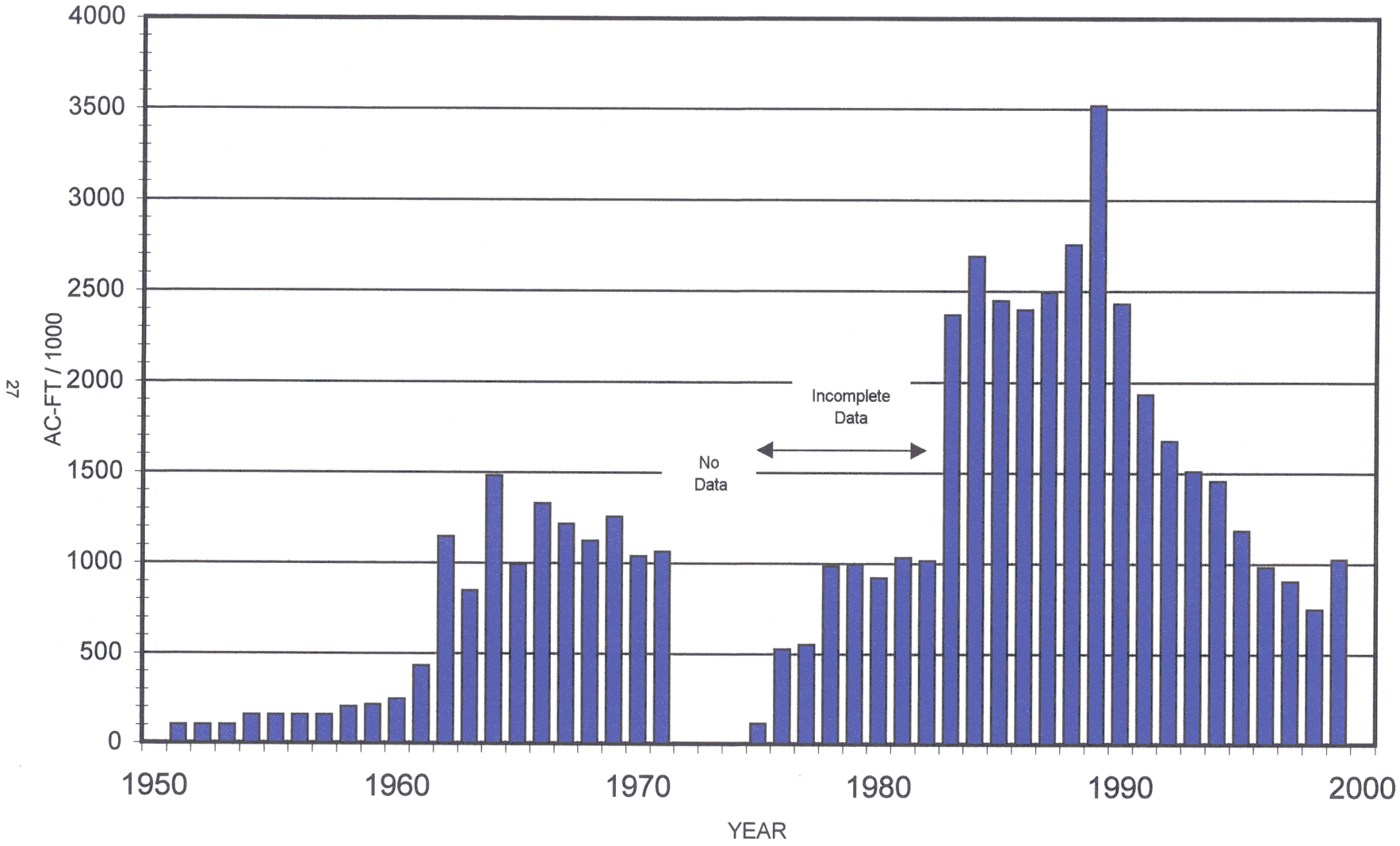

Figure 17 Historical pumpage from the Nevada Test Site

Statistical Relations Between Pumping and Devils Hole Stage -- We have made statistical analyses of the relation between cumulative pumpage in the Amargosa Desert and areas in the Nevada Test Site for the period from 1988 through 1998. Though recovery of Devils Hole stage from the Ash Meadows pumpage was not complete, the recovery phase was in its waning stages. We began to cumulate pumpage starting at 1985 so that time lags could be evaluated. Annual linear regressions were made between Devils Hole stage and the annual pumpage for the Amargosa Desert (fig 18) and Nevada Test Site (fig 19) areas. A multiple linear regression was made for both areas of pumpage. All showed good correlation: Amargosa Desert R^2 = 0.72, Nevada Test Site R^2 = 0.82, and the multiple regression R^2 = 0.82. All suggested a significant statistical relation at less than 1%. The correlations were not significantly improved by one or two-year time lags.

An annual linear regression was made between the pumpage at the Nevada Test Site and Devils Hole stage for the years 1962 through 1969 and 1988 through 1998. This correlation period eliminates the period during which Devils hole stage was greatly affected by nearby Ash Meadows pumping. This correlation was very good with R^2 = 0.987 and a significant statistical relation at less than 1%.

The regressions reported above reveal excellent correlations between cumulative pumpage and Devils Hole stage. However, as previously mentioned cumulative pumpage has a built in trend that will cause it to correlate well with any other variable that exhibits a trend. Consequently, no real significance can be attached to these correlations. We can infer from the principles of ground-water hydrology and our knowledge of the ground-water flow system that a cause-effect relationship exists between ground-water withdrawal and stage in Devils Hole. However, the statistical model merely demonstrates a correlation exits; the correlation does not incorporate the physical dynamics of the system and does not define quantitatively the cause-effect relationship between pumping and Devils Hole stage.

Regional Water-Level Trends

Water level records in areas adjacent to or up-gradient from Devils Hole in the Death Valley Region were examined to detect widespread trends in water level and to place the trends of stage at Devils Hole in a regional perspective. The water-level changes are described below and the hydrographs of wells in these areas are given in Appendix VI.

Ash Meadows -- The longest period of water-level record in Ash Meadows is for Devils Hole which began in 1962. As noted in an earlier section of this report the stage is obviously effected by nearby pumping and recovery, seismic events and loading, and it is inferred that the stage is affected by recharge. These fluctuations appear to be superposed on an overall long term declining trend. Devils Hole well, near Devils Hole and tapping confined basin fill, and the reconstructed hydrograph of Five Springs well (AM-2) have records beginning in 1971 and 1990, respectively, follow trends similar to Devils Hole. The pool level of Devils Hole has exhibited a slight upward trend during 1998 and early 1999. Similar small rises occur in wells AM-1, AM-3 and AM-5.

Water levels in the Ash Meadows area of the Amargosa Desert recovered after the cessation of local irrigation pumping in 1982. The period of water-level rise varied from site to site. The pool level of Devils Hole (AM-4) rose until 1988 and then began a period of gradual decline. Devils Hole well (AM-5) was on a rising trend until 1986 and then began to gradually decline. Point of Rocks North well (AM-6) rose until 1986 and then remained relatively stable with a very slight decline for the next several years. Point of Rocks South well (AM-7) has continued to rise through 1998.

Hydrographs of wells AM-2, AM-4, AM-5 and AM-6 show a rise following the 1992 Landers-Little Skull Mountain earthquakes. This post earthquake fluctuation (as indicated by the monthly data) is typically a rise from middle 1992 to late 1992 that results in an upward offset of the water level followed by a decline tending to follow the declining trend before the rise. A similar response can be recognized in several wells in The Death Valley area, TRAV-W and DV-3, and in the Amargosa Desert, AD-6.

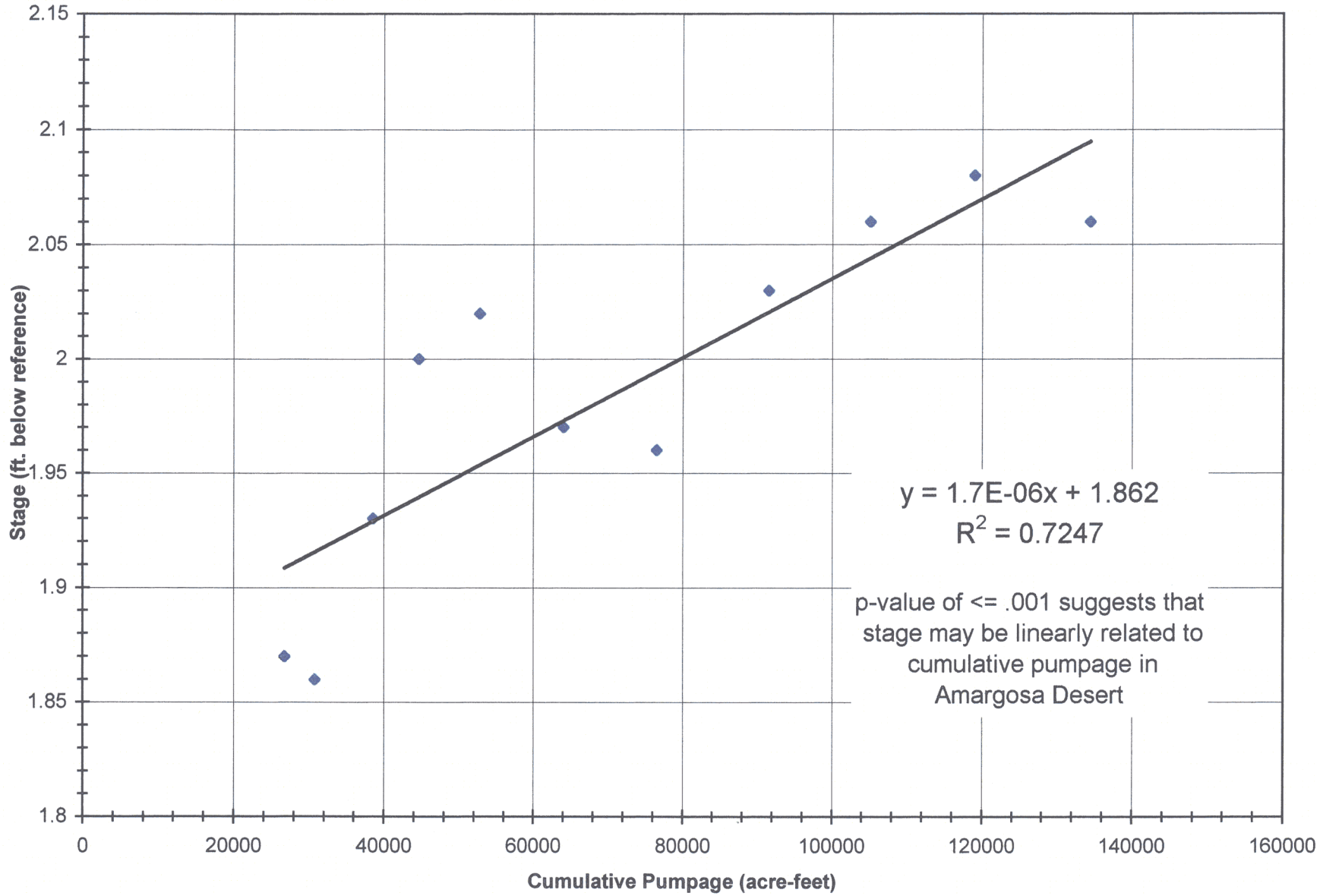

Figure 18. Devils Hole stage versus cumulative pumpage from the Amargosa Desert, 1988-98

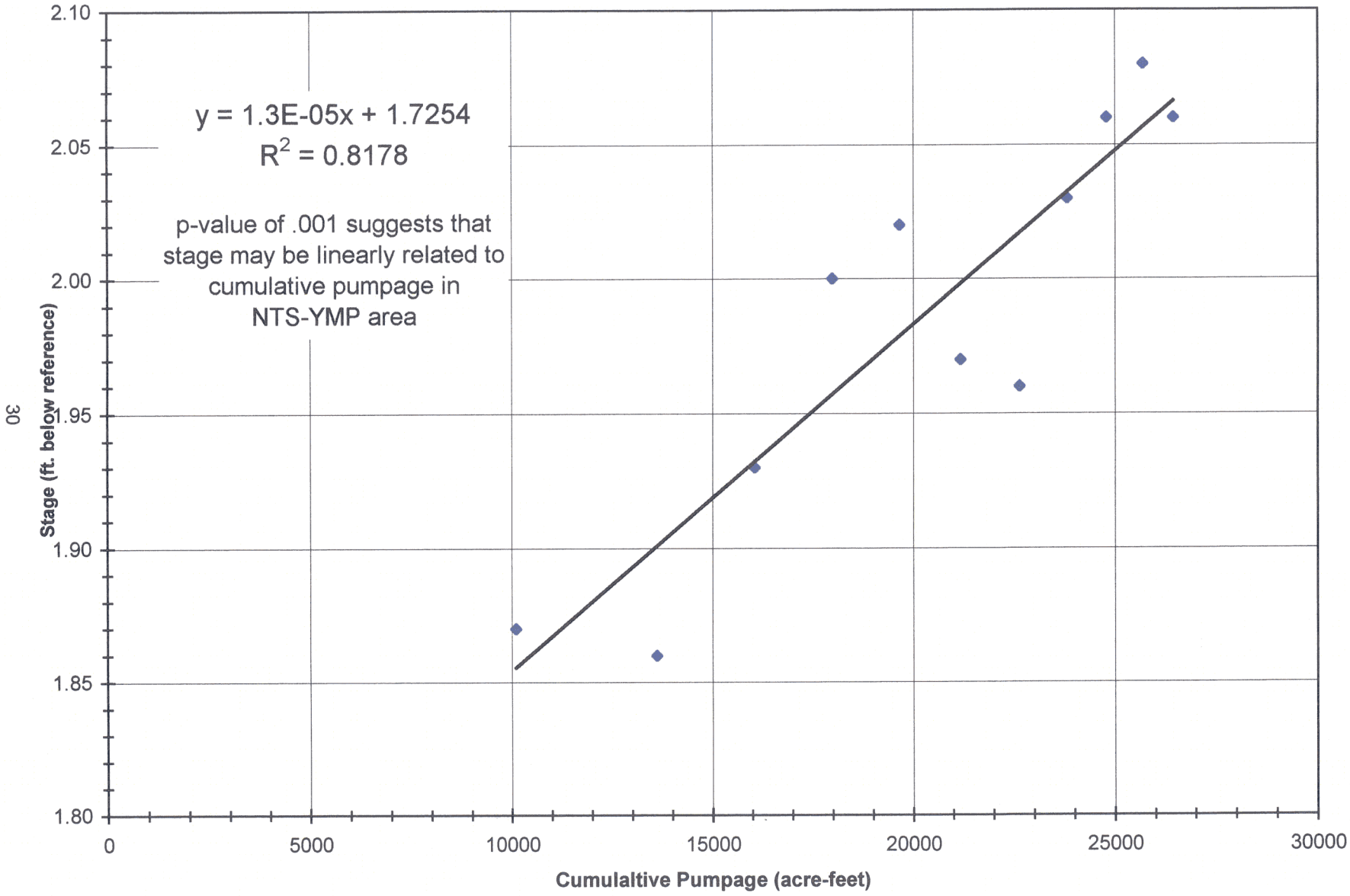

Figure 19. Devils Hole stage versus cumulative pumpage in Nevada Test Site, 1988-98

The record of the Point of Rocks South well (AM-7) is not typical of other wells in carbonate rock in Ash Meadows. The early part of the record, which begins in 1975, shows recovery from the cessation of nearby pumping. Whereas other wells in carbonate rock resumed a declining trend in about 1993, AM-7 has continued to rise through 1999. AM-7 is commonly effected by seismic events. Following a marked coseismic offset in response to the Landers-Little Skull Mountain earthquakes, there appears to be a small permanent offset.

Amargosa Desert -- Most wells in the Amargosa Desert are screened in unconfined basin fill deposits and typically do not respond to seismic events. However, the water level in wells AD-10 and AD-4A exhibit a coseismic water-level offset similar to Devils Hole in response to the Landers-Little Skull Mountain event and well AD-2a appears to shows a coseismic decline.

Water levels throughout much of the farming and developed area of the Amargosa Desert appear to be declining at a rate of one foot or more a year. These declines form a cone of depression in the central part of the Amargosa Desert that is defined not only by this study but was also recognized by Nichols and Akers (1985) who showed an area of about 14 mi^2 where the net decline between 1962 and 1984 exceeded 10 feet. Figure 20 shows the net change in water levels for the 6-year period February 1993 to February 1999 at 49 sites located in the Amargosa Desert, Crater Flat, Jackass Flat, Frenchman Flat, Rock Valley, Mercury Valley, and Death Valley. These changes are tabulated in Appendix VI. This is a period during which a network of wells had been recently established for monthly measurement and it begins at or near the maximum water level recorded in many wells following the Landers earthquake. Net declines were observed in 34 of the sites and a net rise or no change was observed at the remaining 15 sites. Most of the changes were less than one foot The maximum decline observed for the 6-year period used in this study was 11.68 feet. It occurred about two miles southwest of the well where a maximum decline of 27.4 feet between 1972 and 1984 was observed by Nichols and Akers (1985). Allowing for water level declines to occur in the 6-year interval between the two study periods (1985-1992) the maximum historical decline in water level probably exceeded 40 feet as of February 1999. As of 1999 the extent of this cone of depression is not well defined because small water-level declines at the edge of the cone, that are caused by pumping, cannot be easily differentiated from water-level changes due to other factors. However, the changes shown on figure 20 suggest that the edge of the cone of depression may have reached the Ash Meadows area.

Water-level rising trends during 1993-1998 occur in wells AD-11, AD-12, AD-13, and AD-14 located south and southwest of Ash Meadows in the vicinity of Franklin Lake. A negative offset in mid-1995 interrupts the rising trend in well AD-12.

Well AD-6 northeast of and upgradient from Devils Hole, shows a 1993 to 1999 water level trend similar to Devils Hole.

Jackass Flat -- Wells in Jackass Flat show considerable variation in short-term water levels, but there is no prevailing significant rising or falling trend throughout the area. O'Brien (1993) noted coseismic water-level changes in response to the Little Skull Mountain earthquake. Wells JF-3, J-12, and J-13 show gradual declining trends during the 1990's as a result of nearby pumping.

Crater Flat -- Well CF-1A in the northern part of Crater Flat shows a pronounced long-term decline of greater than 15 feet from 1991 to 1999. This is a localized response to pumping for mining purposes. Well CF-2 in central Crater Flat shows a small rising trend of less than one foot from 1984 to 1999 and well CF-3 shows a slight declining trend of less than one foot since 1994.

Mercury Valley -- Wells ARMY 6A and MV-1 have sparse water-level records. An apparent long term declining trend of about 0.1 ft/yr. is indicated in the ARMY 6A well.

Rock Valley -- The one monitoring well in this area, RV-1, shows an overall long-term decline, from the sparse measurements, since the early 1960's. A pronounced decline in water level in 1992 was in response to the Landers-Little Skull Mt. earthquakes and was followed by a rising water level trend in 1994 through October 1999. In October 1999 a sharp decline occurred in response to the Hector Mine earthquake.

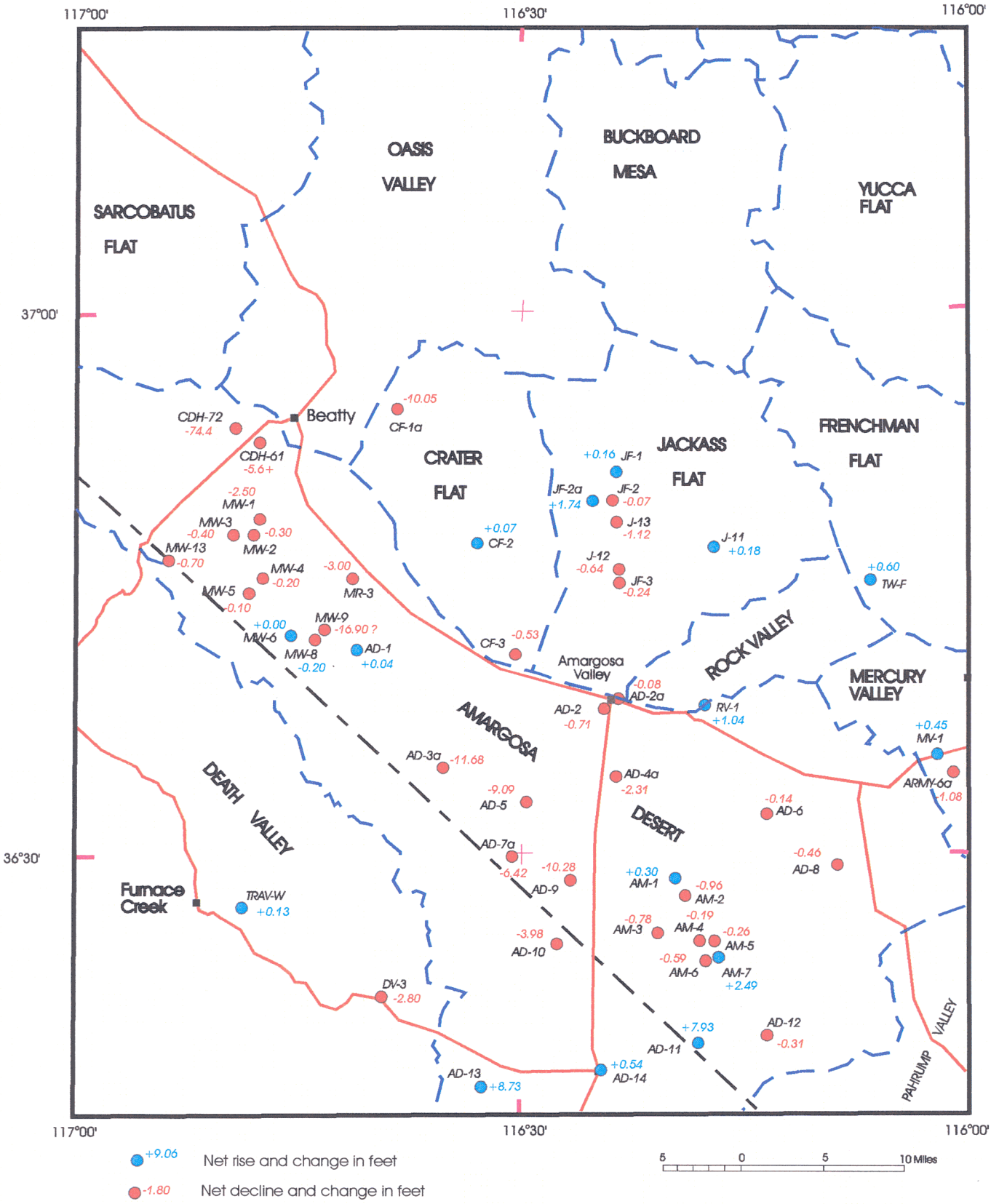

Figure 20 - Net change in water levels 1993-1999 in the Amargosa Desert and Adjacent areas, Death Valley region

Death Valley -- Two monitoring wells in the Furnace Creek Wash area of Death Valley are included in this report. The Travertine Springs well (TRAV-W) is completed in basin-fill of Tertiary age but is believed to be in good hydraulic continuity with the adjacent carbonate rock aquifer. Travertine Point 1 well (DV-3) is in carbonate rock. Both wells show a declining trend since mid-1993 in DV-3 and early 1994 in TRAV-W. The notable feature of both of these hydrographs is that they appeared to be on a declining trend before the Landers-Little Skull Mountain earthquakes in July 1992. Following these earthquakes, both wells show a water-level anomaly, a rising period followed by resumption of a declining trend with an offset above the previous declining trend. This is a response similar to that observed at Devils Hole following the Landers-Little Skull Mountain earthquakes.

Northwestern Las Vegas Valley -- The extreme northwestern part of the Las Vegas Valley hydrographic area is in the Death Valley ground water flow system. Two wells are mentioned for purposes of this study. The locations of these wells are shown on figure 1. Well DR-1 is located on the southeastern flank of the Desert Range, remote from pumping, and is completed in carbonate rock. USAF Well2372-1 is completed in basin fill and is not near any large pumping. The water levels in both wells show a slight rising trend from 1995 to 1999.

Tikaboo Valley -- Well DDL-2 is located in the southern part of Tikaboo Valley (fig. 1) and is completed in carbonate rock. The well is remote from pumping. The water level record from 1992 to 1999 is on a slight rising trend.

Conclusions

1. Stage fluctuations of Devils Hole pool are caused by many factors including earth tides, barometric pressure, seismic disturbances, changes in recharge caused by changes in precipitation, and pumping.

2. The stage record at Devils Hole exhibits an annual cycle where levels are lowest in the winter and highest in the summer. This cycle was attributed to seasonal changes in barometric pressure and a good correlation was found between the mean monthly stage at Devils Hole and mean monthly barometric pressure at a site near Beatty. The correlation suggested a barometric efficiency for Devils Hole of about 0.31. The relation between stage and barometric pressure can be used to adjust the stage to an average barometric pressure. Adjusting the water level hydrograph for barometric change produces significantly less scatter in the data. The annual cycle was removed but several shorter cycles remained.

3. We recommend that tidal and barometric effects be removed from the Devils Hole data as part of the routine processing of the stage record. The USGS has developed some programs that are relatively comprehensive and automated. Consideration should be given to having them do this work.

4. A well-developed cone of depression that coincides generally with the main area of irrigation pumping in the central Amargosa Desert. Rates of decline have exceeded 1 foot per year in part of this area. The maximum net decline observed for the period February 1993 to February 1999 was about 10 feet. The maximum historical decline in this area has probably exceeded 40 feet. The edge of this cone of depression is not well defined because small changes due to pumping are masked by changes due to other factors. However, the edge of the cone of depression may have reached the Ash Meadows area.

5. Pumping for mining in the northwest part of the Amargosa Desert has produced large declines at two sites near a mine. These large declines appear to be highly localized and wells in the rest of this part of the valley typically exhibit relatively small declines.

6. Pumpage in the Amargosa Desert has been increasing. Pumpage in 1998 was reported by the State Engineer to be 15,376 acre-feet compared to 13,902 acre-feet in 1997 and 13,613 acre-feet in 1996. Pumpage at the Nevada Test site and adjacent areas in 1997 was 900 acre-feet, which is down from the maximum rate of 3,500 acre-feet in 1988. Pumpage in Pahrump Valley in 1998 was reported by the

State Engineer to be 27,522 acre-feet compared to 28,879 acre-feet in 1997 and 28,866 acre-feet in 1996.

7. The stage of Devils Hole pool is affected by many factors. However, during given periods of time one or more factors may dominate and control fluctuations of stage. The time intervals and factors thought to be dominant are as follows:

- Pre-1969 – Gradual decline controlled primarily by remote pumping and discharge from flowing wells in Ash Meadows. A component of this decline could be due to below normal precipitation in the recharge areas. This period appears to record a long-term regional declining trend that continues through the period of nearby pumping.
- 1969 to 1982 – Drawdown and recovery. Controlled by nearby pumping and recovery in response to reduced nearby pumping.
- 1983 to 1988 – Rising level. Controlled by recovery after nearby pumping ceased.
- 1989 to 1992 – Gradually declining level. Controlled by remote pumping and regional precipitation.
- 1992 to 1993 – Coseismic drop controlled by response to Landers-Little Skull Mountain earthquakes, followed by a rise and offset from the pre-quake level.
- 1994 to 1997 – Gradual decline, can be projected as a continuation of the gradual decline observed before 1969.
- 1998 to 1999-- Slight rise. Controlled by several years of higher than average precipitation in 1990's.
- Late 1999—Offset decline caused by Hector Mine earthquake.

10. Our evaluation of the report by Avon and Durbin (1994) produced the following comments:

- Three linear regression relations developed between stage and precipitation to explain the decline in stage of Devils Hole pool after 1988 do not accurately project levels forward or backward from the calibration period. The calibration included a period when recovery was the dominant factor that controlled the stage of Devils Hole pool; the regression therefore can not reliably suggest a relationship between stage and precipitation.
- Simple linear regression between precipitation and stage near the terminus of a regional–scale flow system faces many difficulties. The main problem is that the stage is influenced by many factors and it is not feasible to group the weighted effects of all significant factors into a single variable.
- The offset in stage between 1969 and 1988 was attributed to a "more or less permanent dewatering of the valley-fill aquifer due to intensive pumping." Pumping had not caused a permanent dewatering of the aquifer. We believe that the offset in water level between 1969 and 1989 is due to a long-term declining trend that continued during the period of nearby pumping combined with incomplete recovery from local pumping.
- Avon and Durbin (1994) concluded there was no significant relationship between cumulative pumping and Devils Hole stage. We used the same variables and different time periods and produced very good correlations. The statistical model merely demonstrates a correlation exists. It does not incorporate physical dynamics of the system and does not define quantitatively the cause-effect relationship between pumping and Devils Hole stage.

11. Our evaluation of a reports by Lehman and Atkins (1991) and Brown and Lehman (1993) produced the following comment:

- The residuals of trend departures of Devils Hole pool levels had produced a good fit to a cosine function with a period of very close to a year and a magnitude of about 0.07 feet. Lehman and Atkins (1991) concluded that the annual cycle of fluctuation represented response to the annual cycle of pumping or recharge. We present the alternative argument that the annual cycle is the direct result of stress imposed by an annual barometric cycle.

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APPENDIX I

Calculation of Drawdown and Residual Drawdown
at distances of 1 foot and 10,000 feet from a pumped well

The regional trends of stage in Devils Hole are obscured during the period of heavy pumping by wells in Ash Meadows, 1969 through 1975, and during early years of recovery, 1975 through 1988. The magnitude and time response of recovery is an important question in attempting to analyze the water level record. Calculations of drawdown and recovery are used to gain an insight into the magnitude and rate of recovery in relation to distance from the center of pumping.

Calculations of drawdown are made using the Theis equation. Calculation of recovery is made by assuming the pumping continues and superposing on the pumping well an image well (Ferris, 1962) having a negative discharge equal to the original pumping rate. The drawdown at a given time is calculated as the sum of the head changes produced by the real well and the image well. The general theory and procedure is described by Stallman (1962).

For this example a well is pumped at a constant rate of 500 gallons per minute for a period of 5 years and then is allowed to recover for 15 years. The total time of the simulation is 20 years with 5 years of pumping and 15 years of recovery. Two calculations are made one for unconfined conditions and one for confined conditions. Aquifer transmissivity is assumed to be 13,000 ft^2 per day (97,500 gallons per day per foot). The storage coefficient is assumed to be 0.10 for unconfined conditions and 0.0001 for confined conditions. Calculated drawdowns for distances of 1 foot and 10,000 feet are listed below. The 10,000 feet distance is approximately the distance from Devils Hole to the greatest concentration of Ash Meadows pumping. The drawdown is expressed in feet and as a percent of the maximum calculated drawdown.

	DRAWDOWN				% MAXIMUM DRAWDOWN			
	S=0.10		S=0.0001		S=0.10		S=0.0001	
YEAR S	Radius = 1 ft.	Radius = 10,000 ft.	Radius = 1 ft	Radius = 10000 ft	Radius = 1 ft	Radius = 10,000 ft.	Radius = 1 ft	Radius = 10000 ft
0	0.0000	0.0000	0.0000	0.0000	0	0	0	0
1	10.8646	0.3115	14.9242	4.0988	92	30	94	81
2	11.2719	0.5911	15.3316	4.5060	95	57	97	89
3	11.5102	0.7831	15.5699	4.7443	97	75	98	94
4	11.6793	0.9284	15.7389	4.9133	99	89	99	97
5	11.8104	1.0449	15.8701	5.0444	100	100	100	100
6	1.0530	0.8303	1.0530	1.0527	9	79	7	21
7	0.7632	0.6347	0.7362	0.7361	6	61	5	15
8	0.5764	0.5158	0.5764	0.5764	5	49	4	11
9	0.4766	0.4357	0.4766	0.4765	4	42	3	9
10	0.4074	0.3777	0.4074	0.4073	3	36	3	8
11	0.3562	0.3336	0.3562	0.3562	3	32	2	7
12	0.3168	0.2989	0.3168	0.3167	3	29	2	6
13	0.2853	0.2709	0.2853	0.2853	2	26	2	6
14	0.2597	0.2477	0.2597	0.2596	2	24	2	5
15	0.2383	0.2282	0.2383	0.2383	2	22	2	5
16	0.2202	0.2116	0.2202	0.2202	2	20	1	4
17	0.2047	0.1973	0.2047	0.2047	2	19	1	4
18	0.1912	0.1848	0.1912	0.1912	2	18	1	4
19	0.1795	0.1738	0.1795	0.1795	2	17	1	4
20	0.1691	0.1640	0.1691	0.1691	1	16	1	3

Drawdown and recovery unconfined conditions is shown in figure A1-1; drawdown and recovery for confined conditions is shown in figure A1-2. Drawdown is greater near the pumping center; and recovery is within 3 percent of complete after five years, the period of pumping. However, at a distance of 10,000 feet from the pumped well, residual drawdown after 5 years of recovery was 36 percent of the maximum drawdown for unconfined conditions and 8 percent of the maximum drawdown for unconfined conditions. The example shows that at 10,000 feet from the center of pumping, residual drawdown is still significant after a period equal to duration of pumping under either confined and water table conditions. Recovery

after one and one-half times the period of pumping is equal to about 28 percent for unconfined and 6 percent for confined conditions.

At Devils Hole small changes in water level are significant. Pumping was signficantly large from 1969 through 1978. Consequently, small components of change associated with long-term recovery should be considered in evaluations of water-level change.

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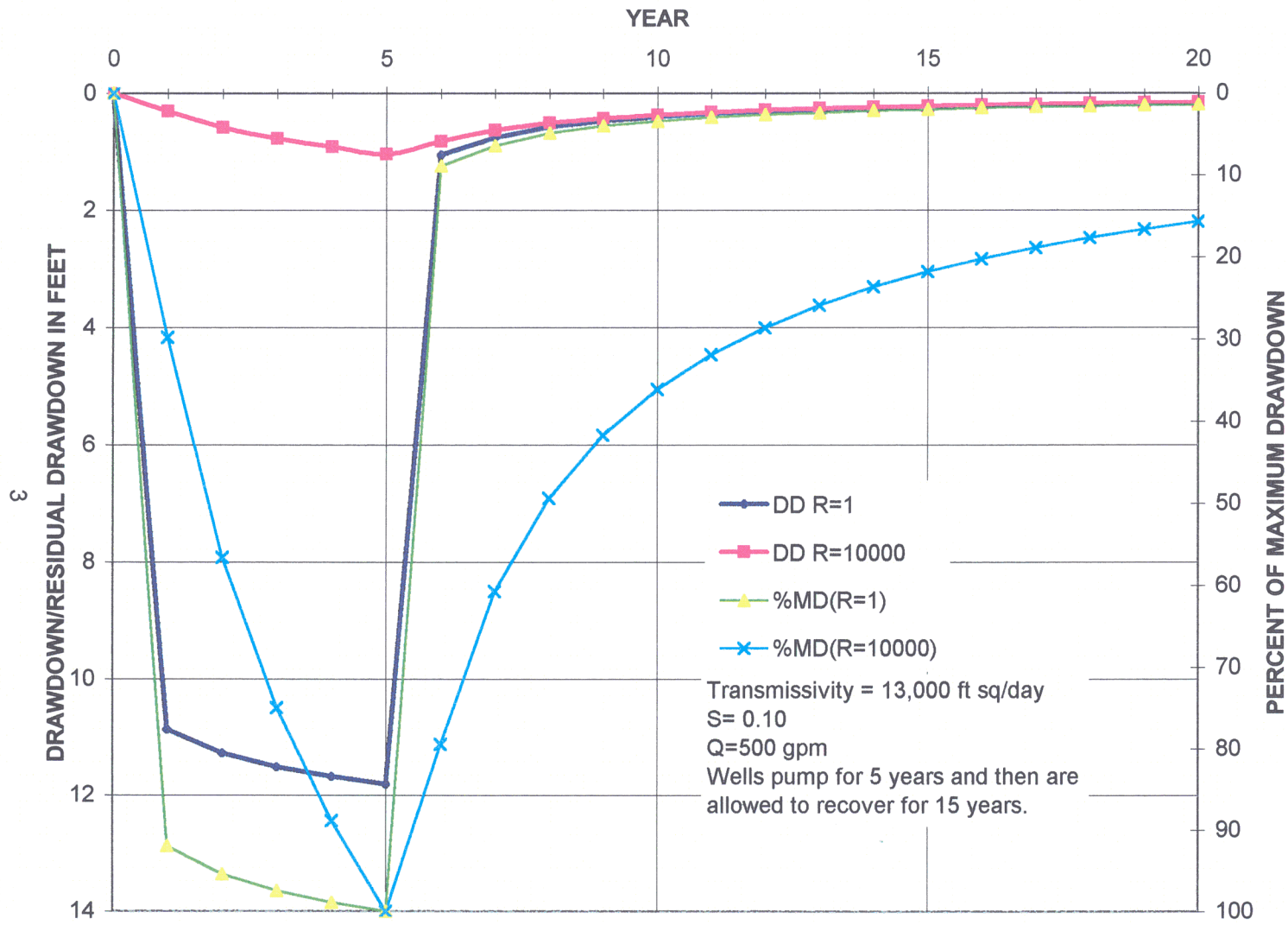

Figure A1-1 Calculated Drawdown and Residual Drawdown at radius of 1 and 10,000 feet (unconfined conditions)

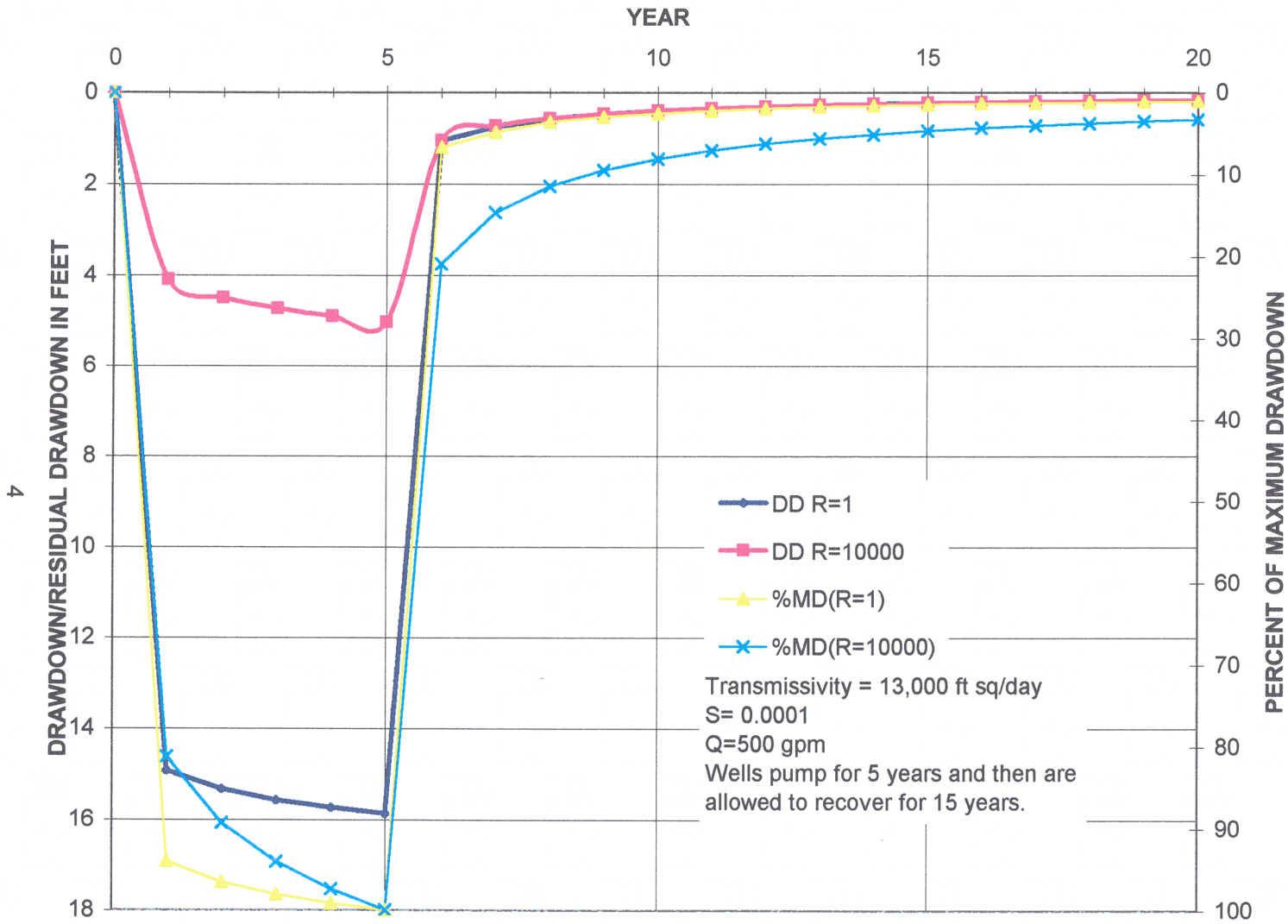

Figure A1-2 Calculated Drawdown and Residual Drawdown at radius of 1 and 10,000 feet (confined conditions)

APPENDIX II

Calculation of Drawdown and Residual Drawdown
at Devils Hole, 1962-2000

These calculations are presented to illustrate that recovery from pumping at Ash Meadows in the 1970's probably will continue beyond the year 2000. The measured water-level rise associated with the recovery continued until 1988 when the pool level at Devils Hole began to decline. Statements to the effect that a component of recovery is still active but is masked by other factors that caused the pool level to decline require supporting information. These calculations provide some of the needed support.

Calculations are made using the Theis equation which greatly oversimplifies the physical properties of the system. The Theis equation assumes that the aquifer is homogeneous and isotropic and that all flow is two-dimensional. In reality basin-fill and carbonate- rock aquifers are present and hydraulically connected in the Ash Meadows-Devils Hole area. Water moves vertically as well as horizontally. Moreover, flow in the carbonate-rock aquifers is primarily through fractures and fracture zones can form preferred localized pathways for flow. The Theis equation also assumes an aquifer of infinite extent but during pumping tests flow boundaries have been observed. Finally, a single storage coefficient value is used to represent the storage properties throughout the aquifer. In reality parts of the aquifer need to be represented by water-table storage coefficients and other parts need to be represented by confined storage coefficients. Because of all these limitations, results obtained using the Theis equation are subject to high uncertainty. Typically, insight gained as a result of performing the detailed evaluation required to set up the calculations may be more significant than the numerical results. All of the findings presented in this Appendix should be considered provisional and should be confirmed by additional analysis using tools that better represent the actual system. One of the most useful results of these calculations may be to focus attention on conditions or issues that need further evaluation.

Image well theory is used to construct a simple analytical model. An image well is used to represent every change in discharge. Annual rates of discharge are used in this analysis. For any given time the sum of the drawdowns calculated for all the image wells represents the drawdown at Devils Hole. Changes in discharge are for pumping wells, flowing wells, an injection well, selected springs, areas of evapotranspiration (ET), and two areas of cleared land. The primary sources of information are as follows:

- Files of the U.S. Geological Survey -- provided estimates of pumpage for each of the Spring Meadows production wells from 1969 until pumping completely ceased in 1982.
- U. S. Geological Survey Professional Paper 927 -- Provided detailed description of the area and an analysis of cause and effect through 1971. This analysis included the documentation of flowing wells prior to pumping, changes in spring discharge, capture of ET by lowering of the water table, and capture of ET by clearing land for production. This detailed documentation of the response provided virtually all of the information used to determine changes in discharge from all sites other than production wells and the injection well. Changes more recent than 1971 were extrapolated from the basic information presented in this report.
- U.S. Geological Survey Open-File Report 80-772 – Provided information about injection of water into the Devils Hole well.

The sites used for image wells are listed in Table A2-1. These sites are shown on figure A2-1. Note that every time that annual discharge changed at a site a new image well was used to represent the change. All of the image wells are listed in Table A2-2 which is the file used to input data into a program that solves the Theis equation for each image well and sums the result for specified time intervals.

For purposes of this calculation a value of 100,000 gpd/ft was used for aquifer transmissivity and a value of 0.10 was use for the storage coefficient. These values gave the best fit between observed and calculated values based on a range of trial values. Well test information presented in Professional Paper 927 shows a wide range of transmissivity values from much lower to more than twice as large as the value selected. The value used in this calculation produces a reasonable approximation of the historical levels however it is not considered representative of the system. To be representative of the system aquifer properties must be

allowed to vary spatially which is beyond the capability of this analysis. The storage coefficient of 0.10 is representative of water table conditions such as would be found in the shallower saturated basin fill in Ash Meadows. Water table conditions may also occur in highly fractured areas of carbonate rock where there is a high vertical hydraulic conductivity however the storage coefficient would probably be lower (perhaps between 0.10 and 0.05). Confined conditions would occur at depth in both basin-fill and carbonate-rock aquifers. Thus the storage coefficient can only be adequately represented when it is allowed to vary spatially which is beyond the capability of this analysis.

Calculations of drawdown were made for the 39 year period beginning 1/1/1962 and ending 12/31/1999. The results are listed below:

Simulation time (years)	Calendar Year	Calculated Drawdown/Residual Drawdown (feet)
0	--	0.0000
1	1962	0.0060
2	1963	0.0035
3	1964	0.0077
4	1965	0.0199
5	1966	0.0334
6	1967	0.0610
7	1968	0.0777
8	1969	0.2494
9	1970	2.4173
10	1971	2.8269
11	1972	2.8043
12	1973	2.1290
13	1974	1.7629
14	1975	2.1521
15	1976	2.2337
16	1977	1.8956
17	1978	1.5394
18	1979	1.2500
19	1980	1.0492
20	1981	0.9511
21	1982	0.9000
22	1983	0.8961
23	1984	0.8744
24	1985	0.8450
24	1986	0.8145
26	1987	0.7851
27	1988	0.7575
28	1989	0.7320
29	1990	0.7084
30	1991	0.6867
31	1992	0.6668
32	1993	0.6483
33	1994	0.6313
34	1995	0.6155
35	1996	0.6009
36	1997	0.5873
37	1998	0.5746
38	1999	0.5628
39	2000	0.5517

Note that in 1988 when the water-level rise in Devils Hole stopped the simulated residual drawdown was still about three quarters of a foot. Recovery continued and at the end of the simulation the residual drawdown was still slightly more than a half foot. The drawdown can be compared to the observed water

level in Devils Hole by adding the drawdown values to 1.1 that represents the pre-pumping water level. The results are shown in figure A2-2. The observed levels shown are mean monthly values for December of each year. These values were selected to eliminate the annual fluctuation and better show trends. The match is fair. The calculated level is more than the observed during peak pumping years and the calculated level during in the 1980's is higher than the observed values. The calculated and observed levels diverge after 1988 but this is expected because that is when the observed values begin to decline. The following general statements are made regarding the results:

- Calculated levels during 1962-69 show a slight declining trend. This calculated trend follows the trend in the observed data although the decline is less. Prior to these calculations climatic variations or response to remote pumping were the only factors being considered as probable causes. The calculated declines are due to the inclusion of discharge from flowing wells. The question raised by this result is: Could the declining trend observed prior to 1969 be attributed to discharge from flowing wells in Ash Meadows?

- A sustained calculated recovery is shown beginning when pumping was reduced in the mid-1970s and continuing through to the end of the simulation. If this is valid then the observed decline since 1988 could be evaluated in terms of the difference between the calculated and observed levels. The difference between the two trends is greater than the magnitude of decline referenced to the 1988 level. Thus the factor or factors causing the post 1988 decline may be having more of a effect than indicated simply by the observed levels. Should the possible influence of continued recovery be included in evaluations of Devils Hole water levels?

- The effect of flowing wells on the calculated levels prior to 1969 raise questions regarding the new equilibrium water level that will represent a full recovery. Because of insufficient data calculations do not assume any resumption of discharge from flowing wells. Information in Professional Paper 927 shows maximum rates of flow for individual wells prior to pumping that total to about 290 gallons per minute. If recovery continues it is possible that total discharge from flowing wells could again approach this rate. If so the flow would ultimately be offset by local reductions in discharge however head in the aquifer would be lower. The amount of lowering is not known but the observed decline from 1962-69 of about 0.3 ft gives an indication that the new level of "full recovery" could be several tenths of a foot below the original level of 1.1 ft below the reference datum. There is not enough information to fully evaluate this possibility but the question raised by this analysis is: Should additional efforts be made to better determine the expected water level when recovery at Devils Hole is complete?

Table A2-1. Sites used in the calculation of water-level drawdown and recovery at Devils Hole, 1962-2000

Map Designation	Name	Distance from Devils Hole (feet)	Source of Information	Remarks
1	Spring Meadows Well No. 1	11,121	USGS files, PP 927	Production well, significant effect on Devils Hole
2	Spring Meadows Well No. 2	11,017	USGS files, PP 927	Production well
3	Spring Meadows Well No. 3	12,264	USGS files, PP 927	Production well, significant effect on Devils Hole. Flowed before being pumped.
4	Spring Meadows Well No. 4	10,185	USGS files, PP 927	Production well, significant effect on Devils Hole
5	Spring Meadows Well No. 5	6,444	USGS files, PP 927	Production well, significant effect on Devils Hole
6	Spring Meadows Well No. 6	8.938	USGS files, PP 927	Production well, flowed before being pumped.
7	Spring Meadows Well No. 7	17,461	USGS files, PP 927	Production well, flowed before being pumped
8	Spring Meadows Well No. 8	23,905	USGS files, PP 927	Production well
13	Spring Meadows Well No. 13	8,315	USGS files, PP 927	Production well
17	Spring Meadows Well No. 17	11,225	USGS files, PP 927	Production well, significant effect on Devils Hole
Soda Sp.	Soda Spring	27,024	PP 927	
Fairbanks Sp.	Fairbanks Spring	28,270	USGS data	Showed string recovery when pumping was shut back, 1975-79
Fairbanks Marsh	Fairbanks Marsh	24,945	PP 927	Point selected to represent capture of ET over a larger area.
Big Spring	Big Spring	24,945	PP 927	Strong response to well 6
Jack Rabbit Sp.	Jack Rabbit Spring	13,720	PP 927	Strong response to well 2
Five Sp.	Five Springs	16,422	PP 927	Response to well 7
Crystal Pool	Crystal Pool Spring	9,562	PP 927	
Misc. Springs & ET	Area where capture from miscellaneous Springs and ET occurred	7,000	PP 927	Distance is radius of the arc of a circle along which capture occurred.
ET area south of 1,2,3	ET area located south of wells 1, 2, and 3	12,224	PP 927	

Map Designation	Name	Distance from Devils Hole (feet)	Source of Information	Remarks
Cleared land S & E of POR	Cleared land located south and east of Point of Rocks	15,383	PP 927	
36dd	Devils Hole well	1,040	USGS OFR 80-772	Used as injection well 1973-77
10cda	Well 17/50-10cda	24,945	PP 927	Flowing well
14cac	Well 17/50-14cac	18,500	PP 927	Flowing well
15aca	Well 17/50-15aca	21,619	PP 927	Flowing well
5aa	Well 18/50-5aa	19,955	PP 927	Flowing well
11dd	Well 18/50-11dd	10,601	PP 927	Flowing well
7db2	Well 18/50-7db2	10,913	PP 927	Flowing well

Table A2-2 Input data file for image wells

```
  202  14235.0000   39          WELLS(I5), TOT TIME(F12.4)(DAYS),# STEPS(I5)
□
2555.0                        1  WELL 1, 1969 BEGIN(I) DAYS (F12.4)
□
200000.0                                   DURATION(I) DAYS (12.4)
11121.0                                    RADIUS(I) FEET (12.4)
446.0                                      Q(I) GPM (F12.4)
2920.00                        2  WELL 1, 1970
200000.0
11121.0
484.0
3285.00                        3  WELL 1, 1971
200000.0
11121.0
310.0
3650.                          4  WELL 1, 1972
200000.0
11121.0
-172.0
4015.0                         5  WELL 1, 1973
200000.0
11121.0
-332.0
4380.0                         6  WELL 1, 1974
200000.0
11121.0
139.0
4745.0                         7  WELL 1, 1975
200000.0
11121.0
-248.0
5110.00                        8  WELL 1, 1976
200000.0
11121.0
-57.0
5475.0                         9  WELL 1, 1977
200000.0
11121.0
-66.0
5840.00                       10  WELL 1, 1978
200000.0
11121.0
-504.0
2555.0                        11  WELL 2, 1969
200000.0
11017.0
174.0
2920.0                         12  WELL 2, 1970
200000.0
11017.0
372.0
3285.0                         13  WELL 2, 1971
200000.0
11017.0
-6.0
3650.0                        14  WELL 2, 1972
200000.0
11017.0
-80.0
4015.0                        15  WELL 2, 1973
200000.0
11017.0
73.0
4380.0                        16  WELL 2, 1974
200000.0
11017.0
226.0
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4745.0                    17  WELL 2, 1975
200000.0
11017.0
-114.0
5110.0                    18  WELL 2, 1976
200000.0
11017.0
-126.0
5475.0                    19  WELL 2, 1977
200000.0
11017.0
-262.0
5840.0                    20  WELL 2, 1978
200000.0
11017.0
-257.0
6570.0                    21  WELL 2, 1980
200000.0
11017.0
17.0
6935.0                    22  WELL 2, 1981
200000.0
11017.0
-9.0
7300.0                    23  WELL 2, 1982
200000.0
11017.0
-8.0
2920.0                    24  WELL 3, 1970
200000.0
12264.0
452.0
3285.0                    25  WELL 3, 1971
200000.0
12264.0
217.0
3650.0                    26  WELL 3, 1972
200000.0
12264.0
-73.0
4015.0                    27  WELL 3, 1973
200000.0
12264.0
-263.0
4380.0                    28  WELL 3, 1974
200000.0
12264.0
-14.0
4745.0                    29  WELL 3, 1975
200000.0
12264.0
15.0
5110.0                    30  WELL 3, 1976
200000.0
12264.0
-2.0
5475.0                    31  WELL 3, 1977
200000.0
12264.0
-192.0
5840.0                    32  WELL 3, 1978
200000.0
12264.0
-214.0
6935.0                    33  WELL 3, 1981
200000.0
12264.0
4.0
7300.0                    34  WELL 3, 1982
200000.0
12264.0
```

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-4.0
2555.0                    35  WELL 4, 1969
200000.0
10185.0
160.0
2920.0                    36  WELL 4, 1970
200000.0
10185.0
415.0
3285.0                    37  WELL 4, 1971
200000.0
10185.0
-273.0
3650.0                    38  WELL 4, 1972
200000.0
10185.0
-304.0
4380.0                    39  WELL 4, 1974
200000.0
10185.0
261.0
4745.0                    40  WELL 4, 1975
200000.0
10185.0
262.0
5110.0                    41  WELL 4, 1976
200000.0
10185.0
-56.0
5475.0                    42  WELL 4, 1977
200000.0
10185.0
-259.0
5840.0                    43  WELL 4, 1978
200000.0
10185.0
-182.0
6205.0                    44  WELL 4, 1979
200000.0
10185.0
138.0
6570.0                    45  WELL 4, 1980
200000.0
10185.0
-162.0
6935.0                    46  WELL 4, 1981
200000.0
10185.0
39.0
7300.0                    47  WELL 4, 1982
200000.0
10185.0
-39.0
2920.0                    48  WELL 5, 1970
200000.0
6444.0
1302.0
3285.0                    49  WELL 5, 1971
200000.0
6444.0
-812.0
3650.0                    50  WELL 5, 1972
200000.0
6444.0
-490.0
4380.0                    51  WELL 5, 1974
200000.0
6444.0
275.0
4745.0                    52  WELL 5, 1975
200000.0
```

```
6444.0
263.0
5110.0                    53  WELL 5, 1976
200000.0
6444.0
-96.0
5475.0                    54  WELL 5, 1977
200000.0
6444.0
-442.0
2555.0                    55  WELL 6, 1969
200000.0
8938.0
21.0
2920.0                    56  WELL 6, 1970
200000.0
8938.0
12.0
3285.0                    57  WELL 6, 1971
200000.0
8938.0
211.0
3650.0                    58  WELL 6, 1972
200000.0
8938.0
-279.0
2920.0                    59  WELL 7, 1970
200000.0
17461.0
25.0
3285.0                    60  WELL 7, 1971
200000.0
17461.0
272.0
3650.0                    61  WELL 7, 1972
200000.0
17461.0
-165.0
4015.0                    62  WELL 7, 1973
200000.0
17461.0
32.0
4380.0                    63  WELL 7, 1974
200000.0
17461.0
-84.0
4745.                     64  WELL 7, 1975
200000.0
17461.0
-80.0
2555.0                    65  WELL 8, 1969
200000.0
23905.0
180.0
2920.0                    66  WELL 8, 1970
200000.0
23905.0
155.0
3285.0                    67  WELL 8, 1971
200000.0
23905.0
-37.0
3650.0                    68  WELL 8, 1972
200000.0
23905.0
-103.0
4015.0                    69  WELL 8, 1973
200000.0
23905.0
-8.0
4380.0                    70  WELL 8, 1974
```

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200000.0
23905.0
-72.0
4745.0                    71  WELL 8, 1975
200000.0
23905.0
-115.0
2555.0                    72  WELL 13, 1969
200000.0
8315.0
205.0
2920.0                    73  WELL 13, 1970
200000.0
8315.0
-205.0
3285.0                    74  WELL 13, 1971
200000.0
8315.0
44.0
3650.0                    75  WELL 13, 1972
200000.0
8315.0
49.0
4015.0                    76  WELL 13, 1973
200000.0
8315.0
-93.0
3650.0                    77  WELL 17, 1972
200000.0
11225.0
1155.0
4015.0                    78  WELL 17, 1973
200000.0
11225.0
-476.0
4380.0                    79  WELL 17, 1974
200000.0
11225.0
-603.0
4745.0                    80  WELL 17, 1975
200000.0
11225.0
101.0
5110.0                    81  WELL 17, 1976
200000.0
11225.0
141.0
5475.0                    82  WELL 17, 1977
200000.0
11225.0
-318.0
2555.0                    83  SODA SP, 1969
200000.0
27024.0
-60.0
4380.0                    84  SODA SP, 1974
200000.0
27024.0
20.0
4745.0                    85 SODA SP, 1975
200000.0
27024.0
15.0
5110.0                    86 SODA SP, 1976
200000.0
27024.0
10.0
5475.0                    87 SODA SP, 1977
200000.0
27024.0
5.0
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5840.0                    88 SODA SP, 1978
200000.0
27024.0
5.0
6205.0                    89 SODA SP, 1979
200000.0
27024.0
5.0
2555.0                    90 ROGERS SP, 1969
200000.0
22450.0
-60.0
4380.0                    91 ROGERS SP, 1974
200000.0
22450.0
20.0
4745.0                    92 ROGERS SP, 1975
200000.0
22450.0
15.0
5110.0                    93 ROGERS SP, 1976
200000.0
22450.0
10.0
5475.0                    94 ROGERS SP, 1977
200000.0
22450.0
5.0
5840.0                    95 ROGERS SP, 1978
200000.0
22450.0
5.0
6205.0                    96 ROGERS SP, 1979
200000.0
22450.0
5.0
2555.0                    97 FB MARSH, 1969
200000.0
24945.0
-20.0
2920.0                    98 FB MARSH, 1970
200000.0
24945.0
-195.0
3285.0                    99 FB MARSH, 1971
200000.0
24945.0
37.0
3650.0                   100 FB MARSH, 1972
200000.0
24945.0
103.0
4015.0                   101 FB MARSH, 1973
200000.0
24945.0
8.0
4380.0                   102 FB MARSH, 1974
200000.0
24945.0
42.0
4745.0                   103 FB MARSH, 1975
200000.0
24945.0
15.0
5110.0                   104 FB MARSH, 1976
200000.0
24945.0
5.0
5475.0                   105 FB MARSH, 1977
200000.0
24945.0
```

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5.0
2920.0                    106 BIG SP, 1970
200000.0
19332.0
-15.0
4380.0                    107 BIG SP, 1974
200000.0
19332.0
-20.0
4745.0                    108 BIG SP, 1975
200000.0
19332.0
-10.0
5110.0                    108A BIG SP, 1976
200000.0
19332.0
-40.0
5475.0                    108B BIG SP, 1977
200000.0
19332.0
35.0
5480.0                    108C BIG SP, 1978
200000.0
19332.0
20.0
6205.0                    108D BIG SP, 1979
200000.0
19332.0
29.0
6570.0                    108E BIG SP, 1980
200000.0
19332.0
1.0
2555.0                    109 JRABBIT SP, 1969
200000.0
13720.0
-100.0
2920.0                    110 JRABBIT SP, 1970
200000.0
13720.0
-400.0
5110.0                    111 JRABBIT SP, 1976
200000.0
13720.0
300.0
5475.0                    112 JRABBIT SP, 1977
200000.0
13720.0
100.0
5840.0                    113 JRABBIT SP, 1978
200000.0
13720.0
100.0
2920.0                    114 FIVE SP, 1970
200000.0
16422.0
-25.0
3285.0                    115 FIVE SP, 1971
200000.0
16422.0
-165.0
3650.0                    116 FIVE SP, 1972
200000.0
16422.0
57.0
4015.0                    117 FIVE SP, 1973
200000.0
16422.0
-31.0
4380.0                    118 FIVE SP, 1974
200000.0
```

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16422.0
84.0
4745.0                  119 FIVE SP, 1975
200000.0
16422.0
78.0
5110.0                  120 FIVE SP, 1976
200000.0
16422.0
1.0
5475.0                  121 FIVE SP, 1977
200000.0
16422.0
1.0
2555.0                  122 CRYSTAL POOL, 1969
200000.0
9562.0
-21.0
2920.0                  123 CRYSTAL POOL, 1970
200000.0
9562.0
-12.0
3285.0                   124 CRYSTAL POOL, 1971
200000.0
9562.0
-592.0
3650.0                  125 CRYSTAL POOL, 1972
200000.0
9562.0
100.0
4015.0                  126 CRYSTAL POOL, 1973
200000.0
9562.0
100.0
4380.0                  126A CRYSTAL POOL, 1974
200000.0
9562.0
218.0
4745.0                  126B CRYSTAL POOL, 1975
200000.0
9562.0
238.0
2555.0                  127 MISC SP, 1969
200000.0
7000.0
-75.0
2920.0                  128 MISC SP, 1970
200000.0
7000.0
-250.0
4380.0                  129 MISC SP, 1974
200000.0
7000.0
115.0
4745.0                  130 MISC SP, 1975
200000.0
7000.0
150.0
5110.0                  131 MISC SP, 1976
200000.0
7000.0
50.0
5840.0                  132 MISC SP, 1978
200000.0
7000.0
10.0
2555.0                  133 ET S OF 1,2,3, 1969
200000.0
12264.0
-25.0
2920.0                  134 ET S OF 1,2,3, 1970
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200000.0
12264.0
-125.0
5475.0                  135 ET S OF 1,2,3, 1977
200000.0
12264.0
75.0
5840.0                  136 ET S OF 1,2,3, 1978
200000.0
12264.0
50.0
6205.0                  137 ET S OF 1,2,3, 1979
200000.0
12264.0
24.0
6570.0                  138 ET S OF 1,2,3, 1980
200000.0
12264.0
1.0
2555.0                  139 CLEARED LAND, 1969
200000.0
15383.0
-200.0
5840.0                  140 CLEARED LAND, 1978
200000.0
15383.0
85.0
6205.0                  141 CLEARED LAND, 1979
200000.0
15383.0
80.0
6570.0                  142 CLEARED LAND, 1980
200000.0
15383.0
25.0
7300.0                  143 CLEARED LAND, 1982
200000.0
15383.0
15.0
7665.0                  144 CLEARED LAND, 1983
200000.0
15383.0
5.0
2555.0                  145 CL POR-DSP, 1969
200000.0
7275.0
-250.0
5840.0                  146 CL POR-DSP, 1978
200000.0
7275.0
100.0
6205.0                  147 CL POR-DSP, 1979
200000.0
7275.0
85.0
6570.0                  148 CL POR-DSP, 1980
200000.0
7275.0
25.0
6935.0                  149 CL POR-DSP, 1981
200000.0
7275.0
25.0
7300.0                  150 CL POR-DSP, 1982
200000.0
7275.0
15.0
4015.0                  151 DH WELL INJ, 1973
200000.0
1040.0
-100.0
```

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4380.0                  152 DH WELL INJ, 1974
200000.0
1040.0
-100.0
5475.0                  153 DH WELL INJ, 1977
200000.0
1040.0
100.0
5840.0                  154 DH WELL INJ, 1978
200000.0
1040.0
100.0
2190.0                  155 FWELL 17/50-10CDA, 1968
200000.0
24945.0
7.5
2555.0                  156 FWELL 17/50-10CDA, 1969
200000.0
24945.0
7.5
2920.0                  157 FWELL 17/50-10CDA, 1970
200000.0
24945.0
-7.5
3285.0                  158 FWELL 17/50-10CDA, 1971
200000.0
24945.0
-5.0
3650.0                  159 FWELL 17/50-10CDA, 1972
200000.0
24945.0
-2.5
2190.0                  160 FWELL 17/50-14CAC, 1968
200000.0
18500.0
35.0
2555.0                  161 FWELL 17/50-14CAC, 1969
200000.0
18500.0
10.0
2920.0                  162 FWELL 17/50-14CAC, 1970
200000.0
18500.0
-25.0
3285.0                  163 FWELL 17/50-14CAC, 1971
200000.0
18500.0
-6.0
3650.0                  164 FWELL 17/50-14CAC, 1972
200000.0
18500.0
-6.0
4015.0                  165 FWELL 17/50-14CAC, 1972
200000.0
18500.0
-8.0
0.0                     166 FWELL 17/50-15ACA, 1962
200000.0
21619.0
18.0
365.0                   167 FWELL 17/50-15ACA, 1963
200000.0
21619.0
7.0
1825.0                  168 FWELL 17/50-15ACA, 1967
200000.0
21619.0
-5.0
2190.0                  169 FWELL 17/50-15ACA, 1968
200000.0
21619.0
```

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-5.0
2555.0                  170 FWELL 17/50-15ACA, 1969
200000.0
21619.0
-5.0
2920.0                  171 FWELL 17/50-15ACA, 1970
200000.0
21619.0
-10.0
1460.0                  172 FWELL 6,           1966
200000.0
8938.0
24.0
1825.0                  173 FWELL 6,           1967
200000.0                    MERGES WITH PUMPED 6 IN
8938.0                      1969 #55
11.0
1460.0                  174 CRYSTAL POOL       1966
200000.0
9562.0
-21.0
1825.0                  175 CRYSTAL POOL       1967
200000.0
9562.0
-10.0
1460.0                  176 FWELL 18/50-5AA    1966
200000.0
19955.0
5.0
2555.0                  177 FWELL 18/50-5AA    1969
200000.0
19955.0
-5.0
1460.0                  178 FWELL 18/50-11DD   1966
200000.0
10601.0
5.0
1825.0                  179 FWELL 18/50-11DD   1967
200000.0
10601.0
10.0
2555.0                  180 FWELL 18/50-11DD   1969
200000.0
10601.0
-10.0
2920.0                  181 FWELL 18/50-11DD   1970
200000.0
10601.0
-5.0
1460.0                  182 FWELL 18/51-7DDB   1966
200000.0
10913.0
20.0
2190.0                  183 FWELL 18/51-7DDB   1968
200000.0
10913.0
-10.0
2555.0                  184 FWELL 18/51-7DDB   1969
200000.0
10913.0
-10.0
2555.0                  185 FWELL 3            1969
200000.0
12264.0
75.0
2920.0                  186 FAIRBANKS SP, 1970
200000.0
28270.0
-400.0
3650.0                  187 FAIRBANKS SP, 1972
200000.0
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28270.0
-50.0
4015.0                    188 FAIRBANKS SP, 1973
200000.0
28270.0
-20.0
4380.0                    189 FAIRBANKS SP, 1974
200000.0
28270.0
-10.0
5110.0                    190 FAIRBANKS SP, 1976
200000.0
28270.0
145.0
5475.0                    191 FAIRBANKS SP, 1977
200000.0
28270.0
145.0
5840.0                    192 FAIRBANKS SP, 1978
200000.0
28270.0
81.0
6205.0                    193 FAIRBANKS SP, 1979
200000.0
28270.0
79.0
6935.0                    194 FAIRBANKS SP, 1981
200000.0
28270.0
20.0
7300.0                    195 FAIRBANKS SP, 1982
200000.0
28270.0
10.0
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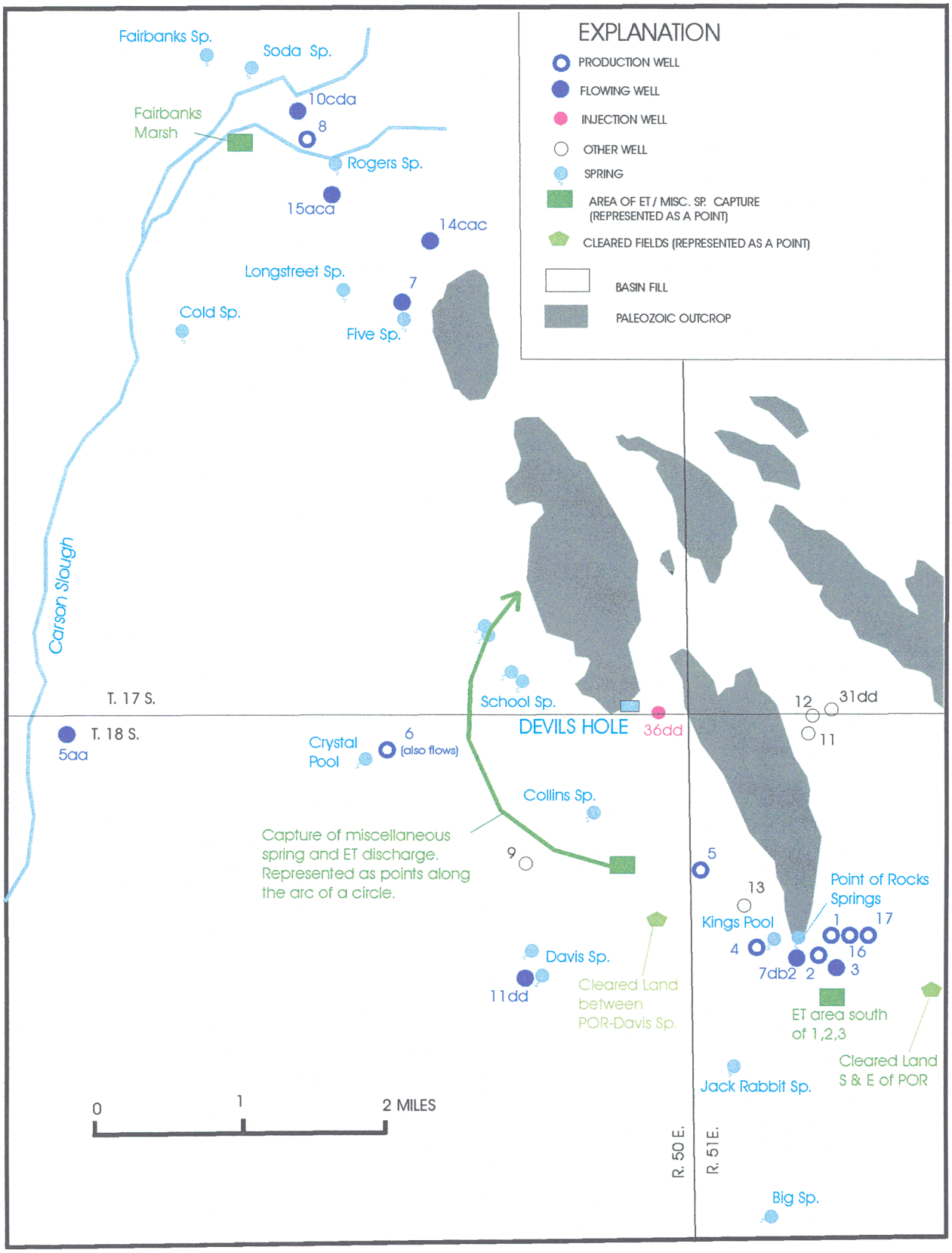


Figure A2-1 Location of wells, springs, and points used to represent capture of ET, Ash Meadows area.

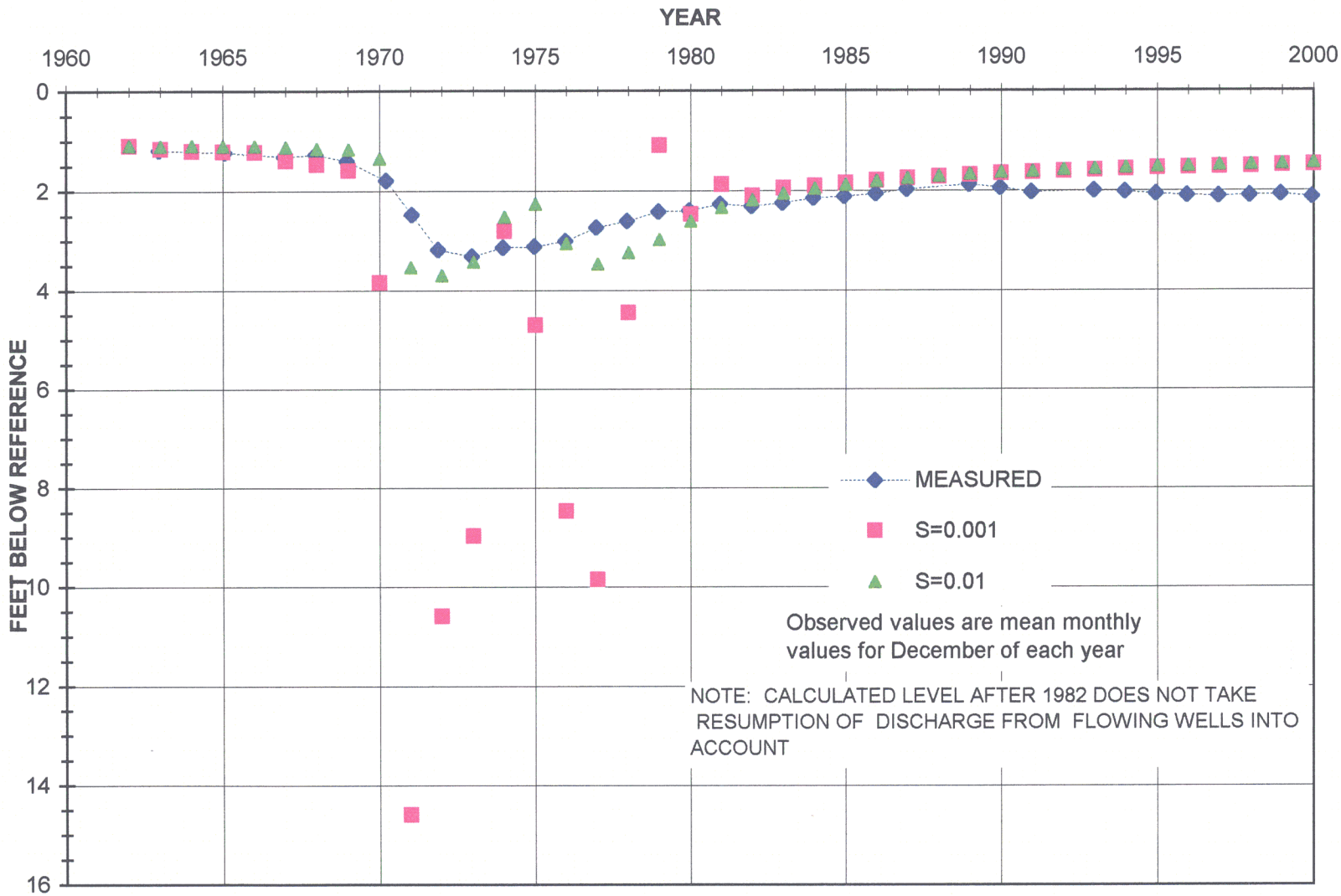


Figure A2-2. Observed and calculated water levels in Devils Hole pool, 1962-2000 (for S=0.001 and S=0.10)

Appendix III- Precipitation data, in inches, for 8 storage gagues in the Spring Mountains
(Data for 1961-92 are from Avon and Durbin 1994, table 6. Remaining years are from data furnished by the Nevada State Engineer)

YEAR	#1	#2	#3	#4	#5	#6	#7	#8
1961	*11.06*	5.90	19.80	12.75	6.30	*3.95*	*13.58*	*6.06*
1962	*20.95*	16.25	*17.75*	30.40	14.10	*7.76*	13.80	*14.64*
1963	*12.37*	6.17	*10.63*	15.65	8.00	*3.58*	8.25	*6.45*
1964	*10.76*	8.00	11.50	*17.04*	*9.07*	*3.26*	*8.72*	9.20
1965	*12.13*	10.10	12.20	21.15	11.50	*4.68*	16.90	13.00
1966	*15.67*	11.85	18.71	23.60	18.70	7.85	18.05	12.55
1967	18.60	13.05	18.40	24.50	15.85	*7.23*	10.00	9.60
1968	23.20	14.20	22.20	24.80	13.00	6.95	9.80	*13.04*
1969	31.00	*25.14*	29.70	39.20	20.90	*15.16*	21.00	9.10
1970	13.20	*13.93*	14.50	*16.96*	10.80	9.70	9.20	*13.03*
1971	17.05	17.20	16.10	*21.27*	11.60	10.80	10.20	10.50
1972	16.80	17.20	15.30	24.20	18.50	*9.58*	7.00	13.80
1973	27.30	23.90	26.10	12.20	*17.64*	*15.03*	18.60	*15.19*
1974	10.30	11.10	14.50	17.70	*10.76*	3.60	6.80	8.80
1975	12.60	17.60	17.60	12.50	14.95	*10.08*	15.70	17.40
1976	12.00	*12.19*	11.25	18.30	8.10	5.45	6.90	11.30
1977	18.00	16.30	17.85	33.00	10.00	6.10	11.00	13.80
1978	33.03	26.00	34.10	*33.31*	*19.61*	18.30	28.50	*25.87*
1979	24.46	*21.02*	22.50	*26.20*	15.95	13.60	18.45	*19.90*
1980	24.85	*23.51*	27.30	*26.67*	15.60	17.70	21.90	*22.39*
1981	10.80	9.20	14.20	13.75	8.00	6.70	9.10	*10.88*
1982	21.90	21.10	25.50	21.40	17.05	12.70	8.10	*18.51*
1983	27.50	27.35	31.25	32.10	*19.77*	18.85	*19.26*	*23.94*
1984	16.20	16.30	15.90	16.90	4.80	14.00	15.00	*16.94*
1985	28.85	*26.43*	33.25	25.85	*20.53*	14.25	24.30	19.55
1986	19.00	22.20	24.35	24.20	13.35	11.70	12.90	18.10
1987	22.00	18.60	18.10	23.50	15.20	8.85	15.87	17.25
1988	21.35	17.90	12.30	23.80	15.25	10.50	20.15	19.50
1989	17.70	16.45	11.55	18.65	11.85	8.60	12.95	11.95
1990	15.65	15.45	15.55	17.35	11.30	7.25	11.60	13.90
1991	16.55	19.15	19.55	23.25	15.60	10.05	15.65	15.80
1992	23.80	24.55	27.30	30.75	19.35	16.35	19.70	23.65
1993	29.00	29.90	31.65	31.95	24.80	17.90	22.85	28.20
1994	12.50	12.50	14.20	15.50	9.05	4.80	8.15	10.20
1995	30.75	30.30	35.10	36.60	27.45	18.90	24.75	25.60
1996	16.80	*14.71*	15.10	16.40	12.60	9.00	8.60	12.20
1997	31.90	38	36.25	28.75	26.50	20.00	30.50	31.95

Appendix IV - Precipitation data, in inches, for two stations on Pahute Mesa.
(Data for 1965-92 are from Avon and Durbin 1994, figs 11 & 12.
Remaining years are from data furnished by the Desert Research Institute)

Calendar Year	Station 84	Station 86
1965	12.96	5.95
1966	14.01	10.42
1967	10.98	8.33
1968	11.64	10.14
1969	23.94	9.34
1970	10.89	3.90
1971	8.78	5.25
1972	8.36	8.90
1973	20.20	9.70
1974	8.35	3.93
1975	12.52	7.93
1976	15.81	7.06
1977	13.31	9.69
1978	27.76	12.78
1979	12.08	5.95
1980	10.76	7.08
1981	9.14	4.19
1982	13.35	6.63
1983	23.72	11.90
1984	12.39	5.66
1985	14.32	10.57
1986	11.55	4.88
1987	14.58	8.38
1988	14.71	8.81
1989	6.94	4.82
1990	6.59	3.97
1991	9.22	6.56
1992	18.05	8.73
1993	15.50	7.89
1994	8.03	5.15
1995	21.50	9.19
	Ave 69-92	Ave 65-92
	13.46	7.55

APPENDIX V

Historical pumpage for Amargosa Desert, Pahrump Valley , and Nevada Test Site (includes pumpage from adjacent areas of Jackass Flat for Yucca Mountain Project)

Year	Amargosa Desert (acre-feet)	Pahrump Valley (acre-feet)	Nevada Test Site (acre-feet)
1950		13,100	
1951		16,100	100
1952			100
1953		26,200	100
1954		25,100	160
1955		27,200	160
1956		23,300	160
1957		21,300	160
1958		22,900	200
1959		24,200	210
1960		25,300	250
1961		28,500	430
1962		27,600	1,150
1963	3,000	31,200	850
1964		36,200	1,480
1965		35,700	1,000
1966	4,203	37,000	1,330
1967	9,282	40,400	1,220
1968	9,043	47,100	1,130
1969		40,200	1,260
1970		42,200	1,040
1971		37,200	1,070
1972		35,900	
1973	7,124	38,800	
1974		41,000	
1975		40,600	110
1976		44,500	530
1977		42,900	550
1978		34,300	990
1979			1,000
1980			920
1981			1,040
1982			1,020
1983		23,200	2,370
1984		24,400	2,690
1985	9,682	23,100	2,450
1986	7,248	19,400	2,400
1987	5,761	19,200	2,500
1988	4,110	19,700	2,760
1989	3,921	20,100	3,520
1990	7,807	21,000	2,430
1991	6,122	24,900	1,930
1992	8,114	23,289	1,680
1993	11,300	20,962	1,510
1994	12,451	24,884	1,460
1995	15,035	23,621	1,180

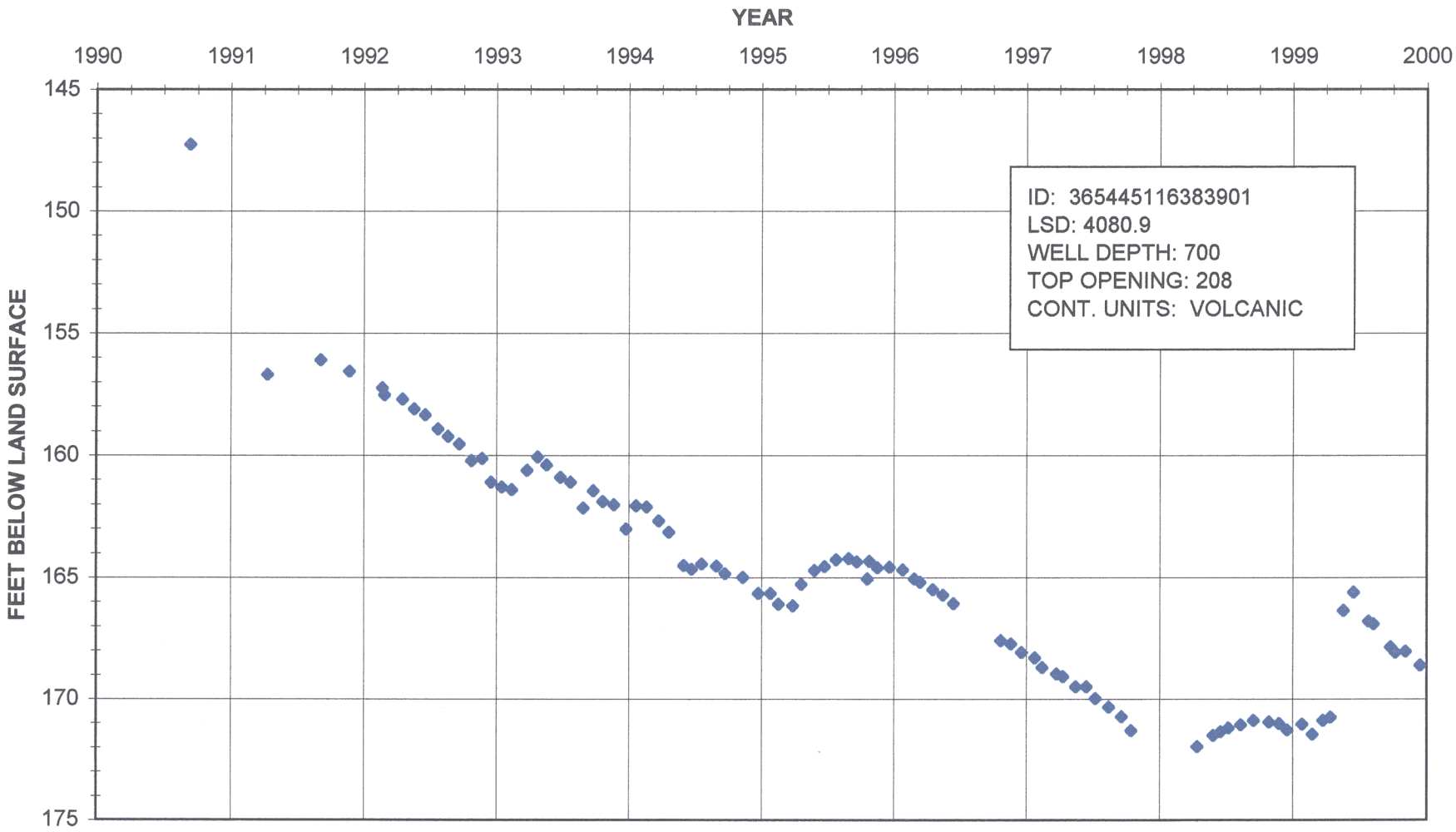
Year	Amargosa Desert (acre-feet)	Pahrump Valley (acre-feet)	Nevada Test Site (acre-feet)
1996	13,613	28,866	990
1997	13,902	28,879	900
1998	15,736	27,522	740
1999			1,030

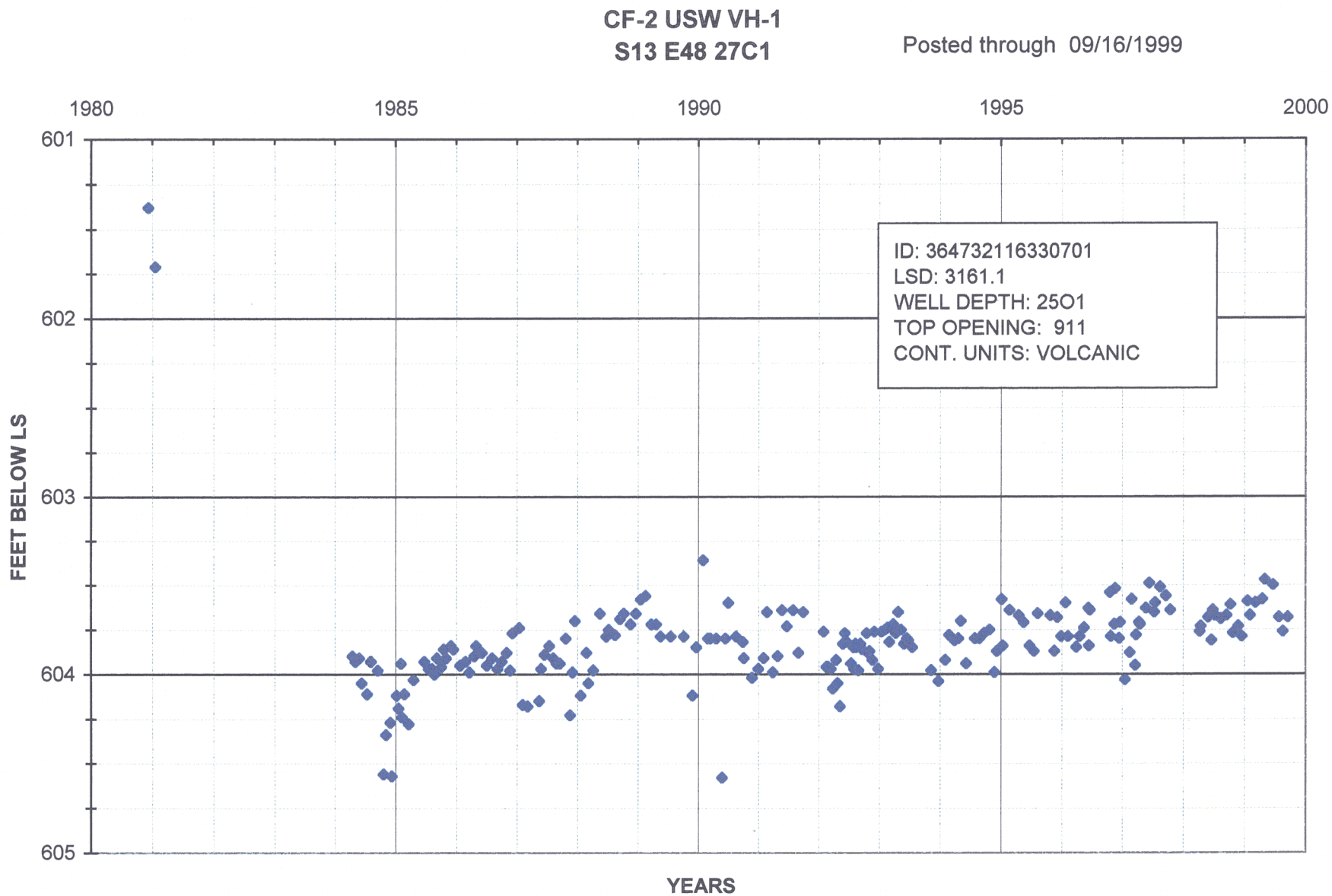
APPENDIX VI List of Hydrographs

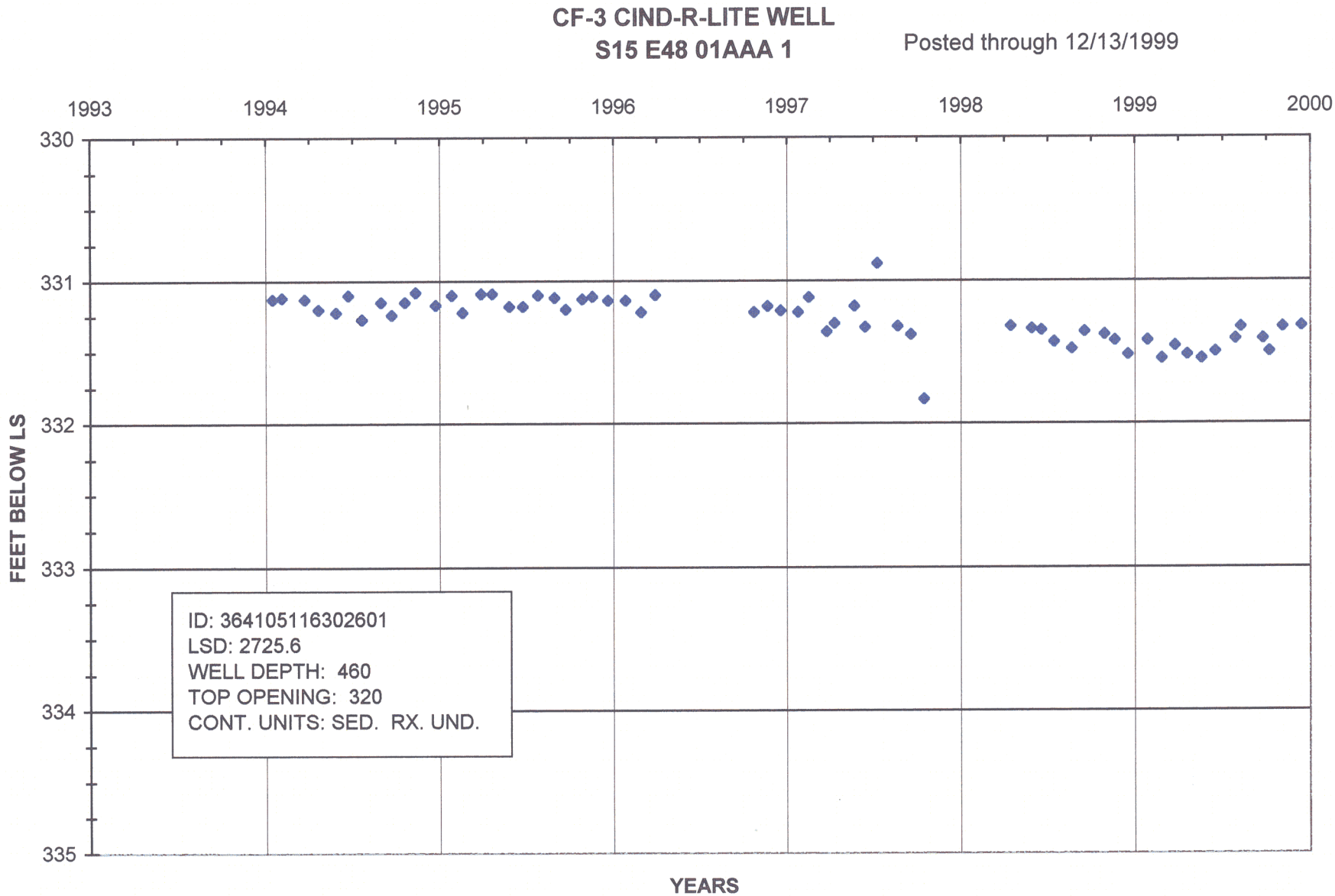
Site Number	Hydrographic Area	Site Location	Site Name	Page
Crater Flat Wells				
CF-1A	229	S12E4807ADD1	Gexa Well 3	2
CF-2	229	S13E4827C1	USW VH-1	3
CF-3	229	S15E4801AAA1	Cind-R-Lite Well	4
Jackass Flat Wells				
JF-1	227A	S12E5033A1	UE- 25 WT 15	5
JF-2	227A	S13E5018B1	UE - 25 WT 13	6
JF-2A	227A	S13E4914A1	UE - 25p 1 PTH	7
J-11	227A	S13E5131B1	J-11 WW	8
J-12	227A	S14E5006A1	J-12 WW	9
J-13	227A	S13E5019C1	J-13 WW	10
JF-3	227A	S14E5006D1	JF-3 WW	11
Rock Valley Wells				
RV-1	226	S15E5024A1	TW-5	12
Mercury Valley Wells				
MV-1	225	S16E5305ADB1	Army 1 WW	13
ARMY-6A	225	S16E5309AC1	Army Well 6A	14
Amargosa Desert Wells				
AD-1	230	S14E4732DA1	NA-6 Well BGMW-10	15
AD-2	230	S15E4924ABB1	Airport Well	16
AD-2A	230	S15E5018CCDB1	NDOT Well	17
AD-3A	230	S16E4805CAB1	Davidson Well	18
AD-4A	230	S16E5007CABB1	Cooks East Well	19
AD-5	230	S16E4918DCCA1	USBLM Well	20
AD-6	230	S16E5127BAA3	Tracer Well 3	21
AD-7A	230	S17E4801AB2	Blackman Well	22
AD-8	230	S17E5208CDB1	Cherry Patch Well	23
AD-9	230	S17E4915BBBB1	Gilgans North Well	24
AD-10	230	026N005E05E001S	NA-9 Well	25
AD-11	230	S19E5001BBD1	GS-3 Well	26
AD-12	230	S18E5134CBD1	Gs-1 Well	27
AD-13	230	025N004E21M001S	S-1 Well	28
AD-14	230	025N005E14M001S	Death Valley Junction Well	29
MR-3	230	S13E4735BDBA1	MR-3 Well	30
MW-1	230	S13E4610DB1	Barrick Gold Monitoring Well-1	31
MW-2	230	S13E4615DB	Barrick Gold Monitoring Well-2	32
MW-3	230	S13E4616AD	Barrick Gold Monitoring Well 3	33
MW-4	230	S13E4635DA	Barrick Gold Monitoring Well 4	34
MW-5	230	S14E4608CB	Barrick Gold Monitoring Well 5	35
MW-6	230	S14E4626BA	Barrick Gold Monitoring Well 6	36
MW-8	230	S14E4825BD	Barrick Gold Monitoring Well 8	37
MW-9	230	S14E4625AA	Barrick Gold Monitoring Well 9	38
MW-11	230	S14E4830CD	Barrick Gold Monitoring Well 11	39
MW-13	230	S13E4525C	Barrick Gold Monitoring Well 13	40
CDH-61	230	S12E4622AC	Abandoned in 1997	41
CDH-72	230	S12E4616DD		42
Ash Meadows Wells				
AM-1	230	S17E5010CDD1	Rogers Spring Well	43
AM-2	230	S17E5023BBCA1	Five Springs Well (head & flow)	44
			Relation between head and flow	45
			Reconstructed shut-in head	46
AM-3	230	S17E5033CAAB1	Garners Well	47
AM-4	230	S17E50	Devils Hole	48
AM-5	230	S17E5036DDC1	Devils Hole Well	49
AM-6	230	S18E5107BBBB1	Point of Rocks North Well	50
AM-7	230	S18E5107BDB1	Point of Rocks South Well	51
Death Valley Wells				
DV-3	243	026N003E21L001S	Travertine Point 1 Well	52
TRAV-W	243	027N001E24E001S	Travertine Springs Well	53
Frenchman Flat Wells				
TW-F	160	S14E5205DD1	TW-F Well	54
Tikapoo Valley Wells				
DDL-2	169B	S12E6010AD		55
Las Vegas Valley Wells				
DR-1	212	S16E5814A		56
USAF Well 2372-1	212	S17E5814BA1		57

CF-1A GEXA WELL 3
S12 E48 07ADD1

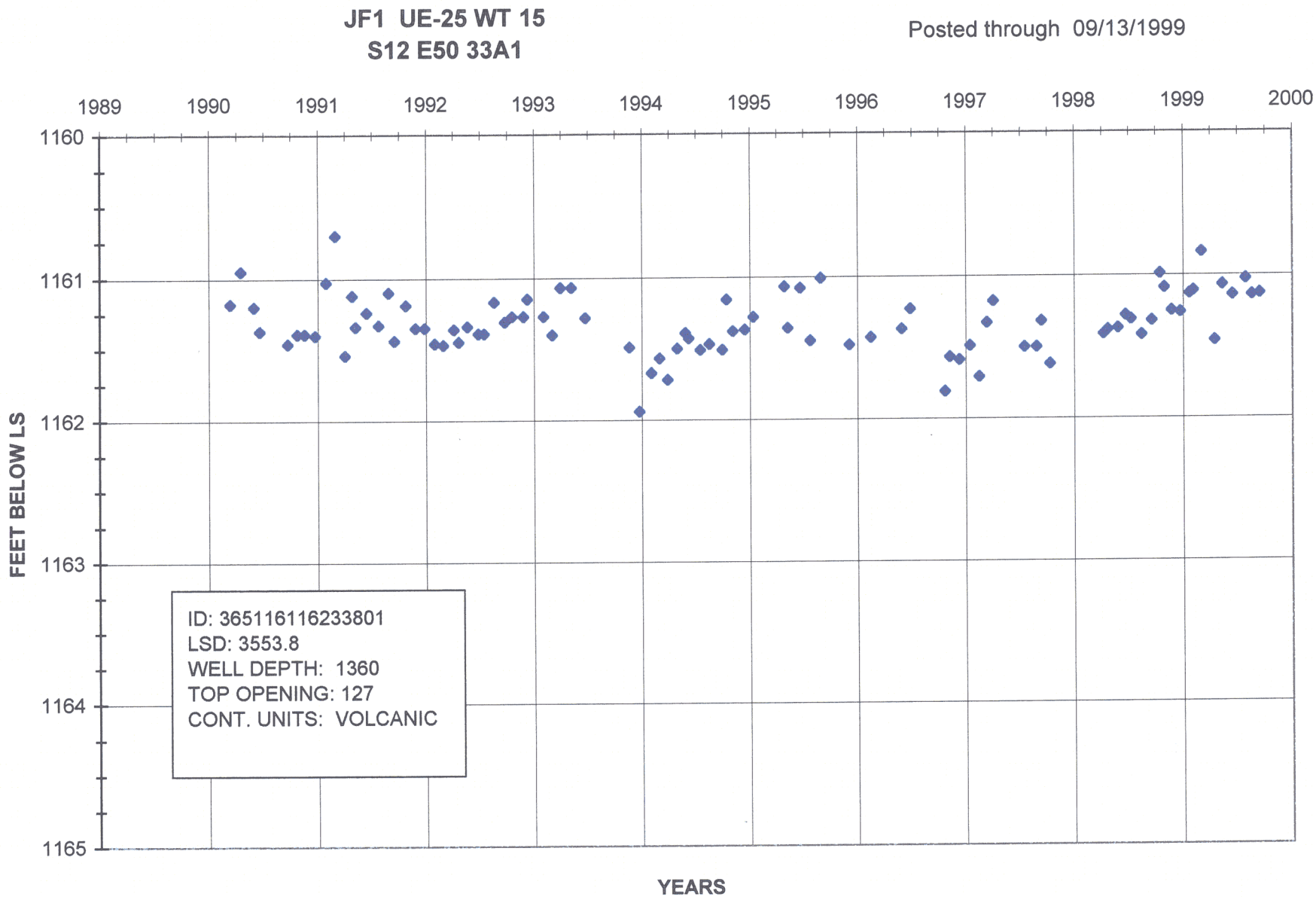
Posted through 12/13/1999



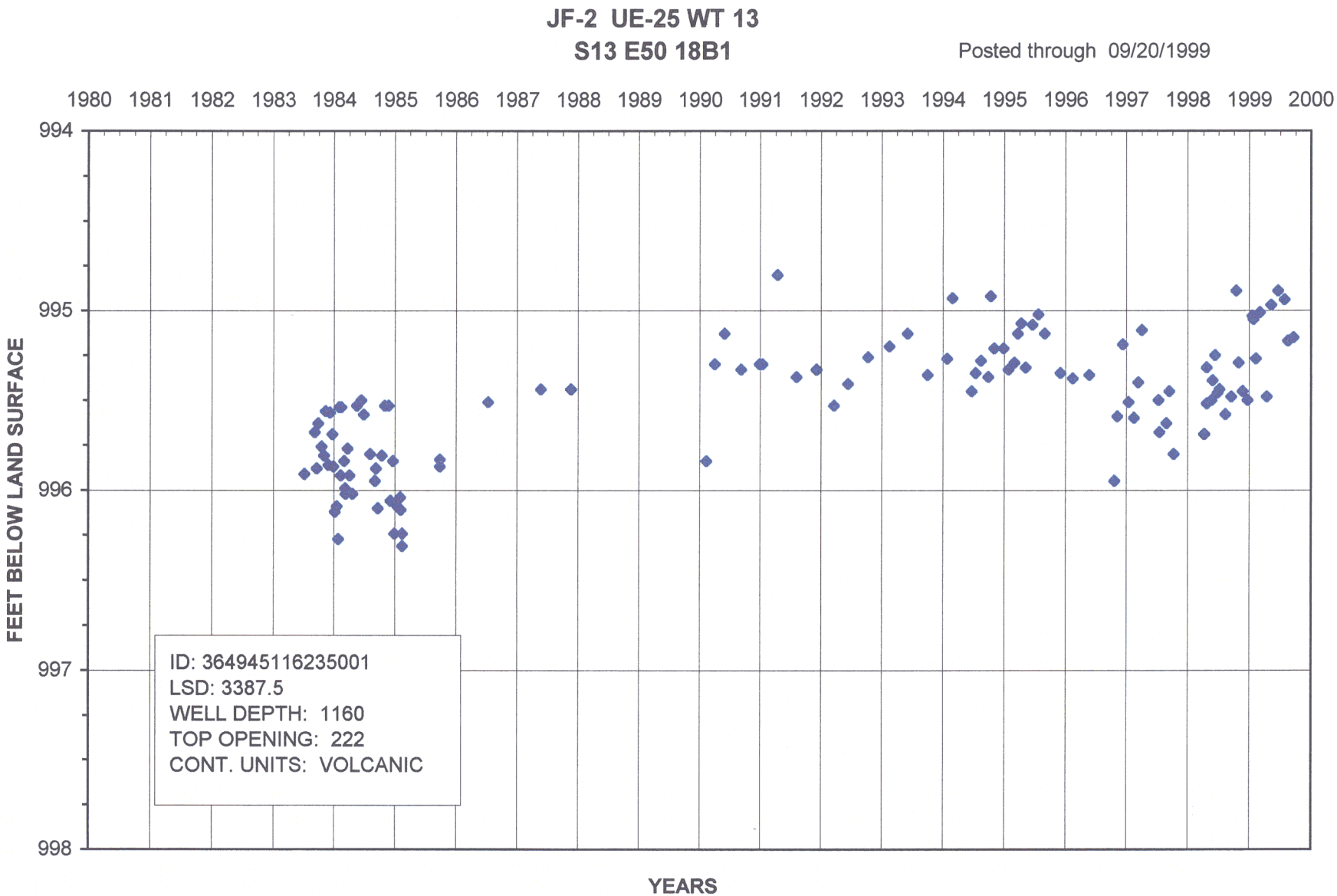

CF-2 USW VH-1
S13 E48 27C1
Posted through 09/16/1999
1980
1985
1990
1995
2000
601
602
603
604
605
FEET BELOW LS
YEARS
ID: 364732116330701
LSD: 3161.1
WELL DEPTH: 25O1
TOP OPENING: 911
CONT. UNITS: VOLCANIC

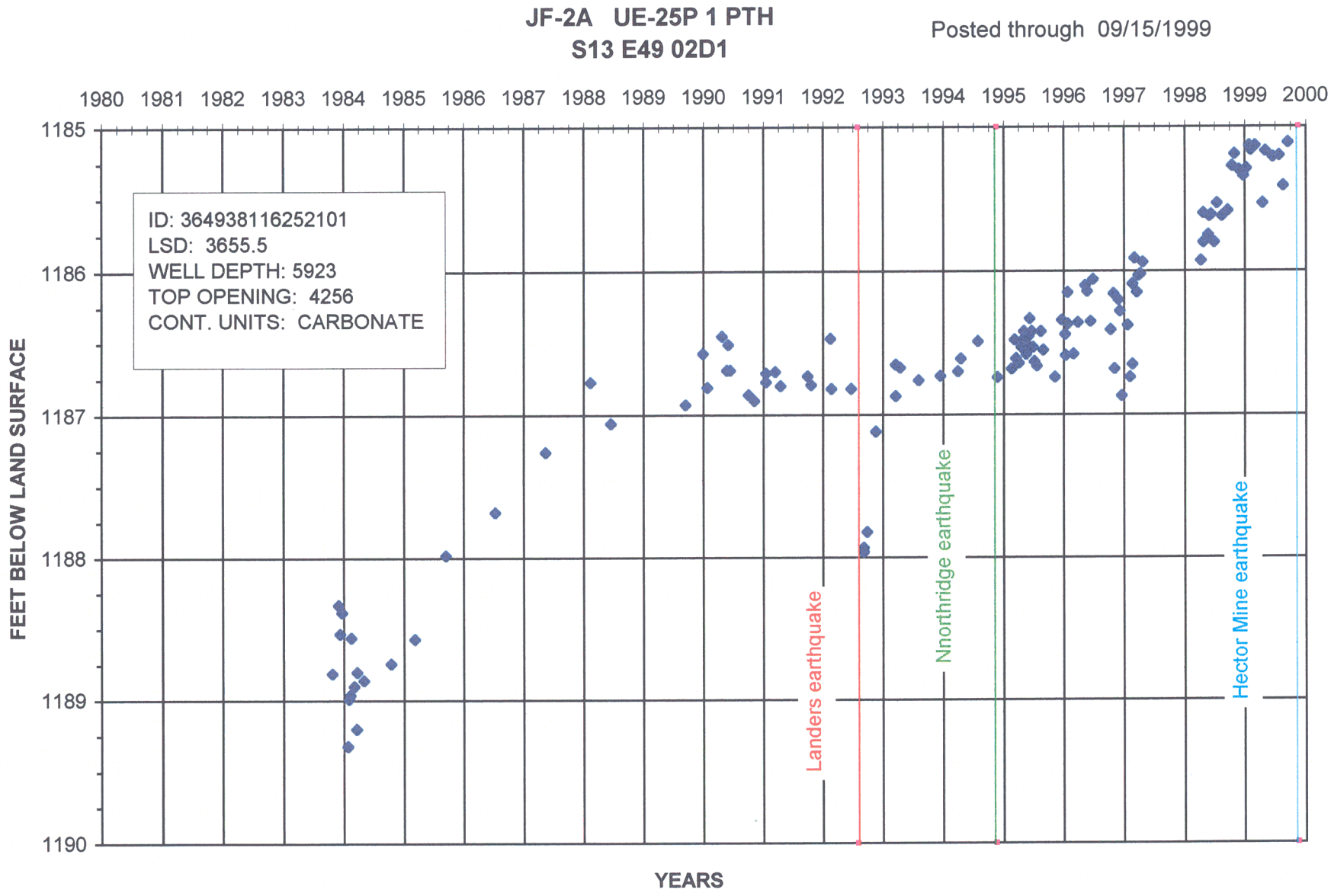


Hydrograph of well CF-3

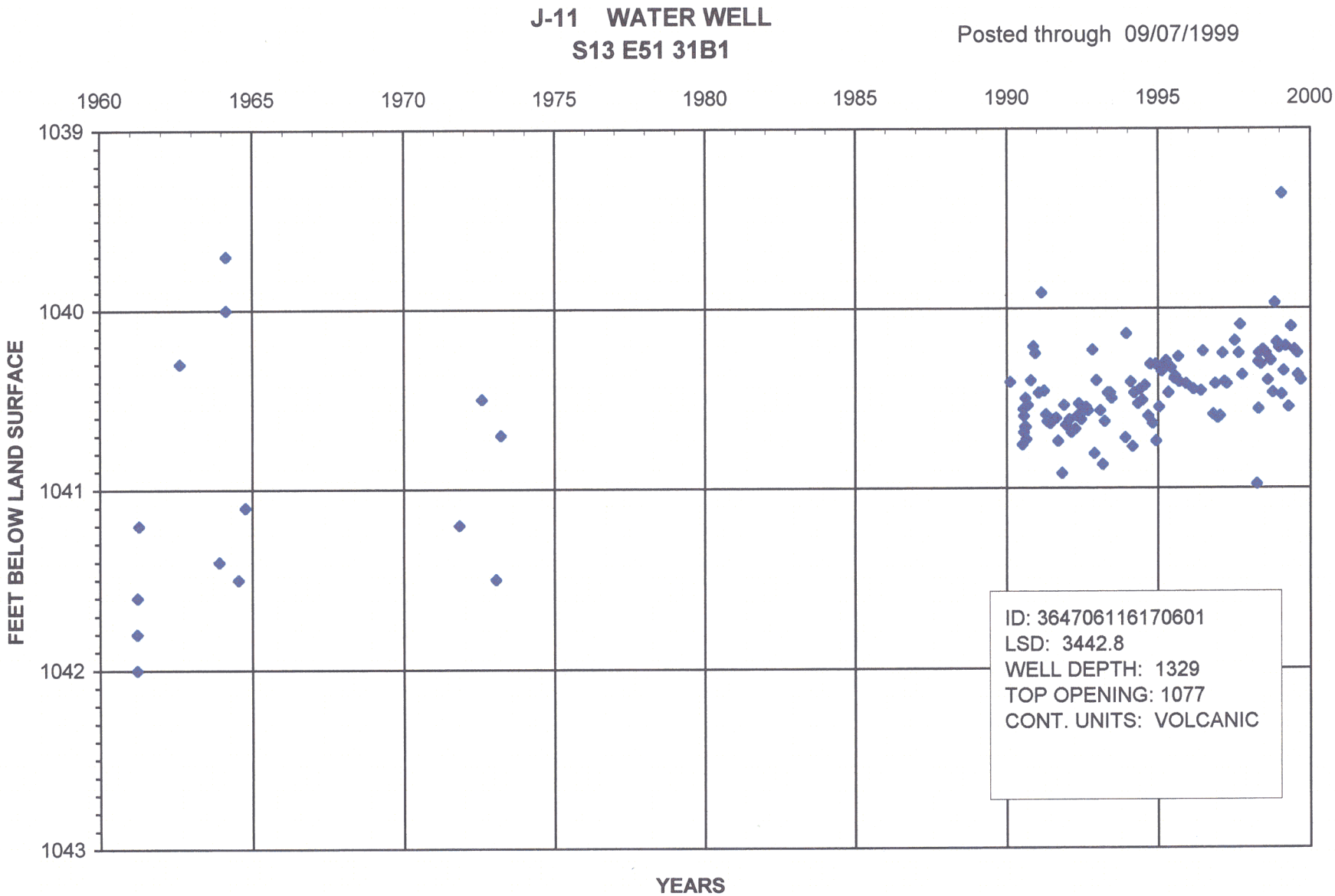


Hydrograph of well JF-1

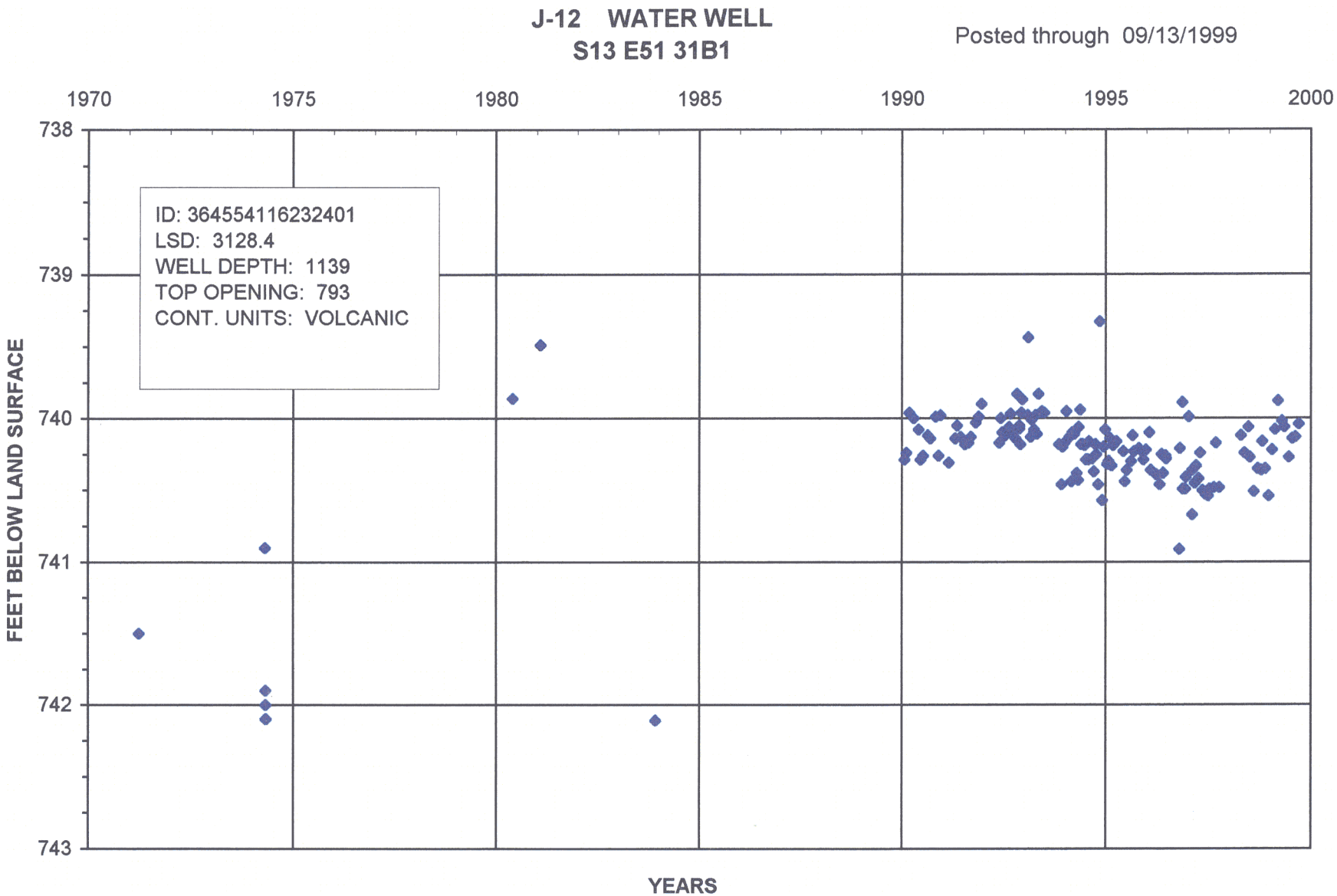

JF-2 UE-25 WT 13
S13 E50 18B1
Posted through 09/20/1999
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
994
995
996
997
998
FEET BELOW LAND SURFACE
YEARS
ID: 364945116235001
LSD: 3387.5
WELL DEPTH: 1160
TOP OPENING: 222
CONT. UNITS: VOLCANIC

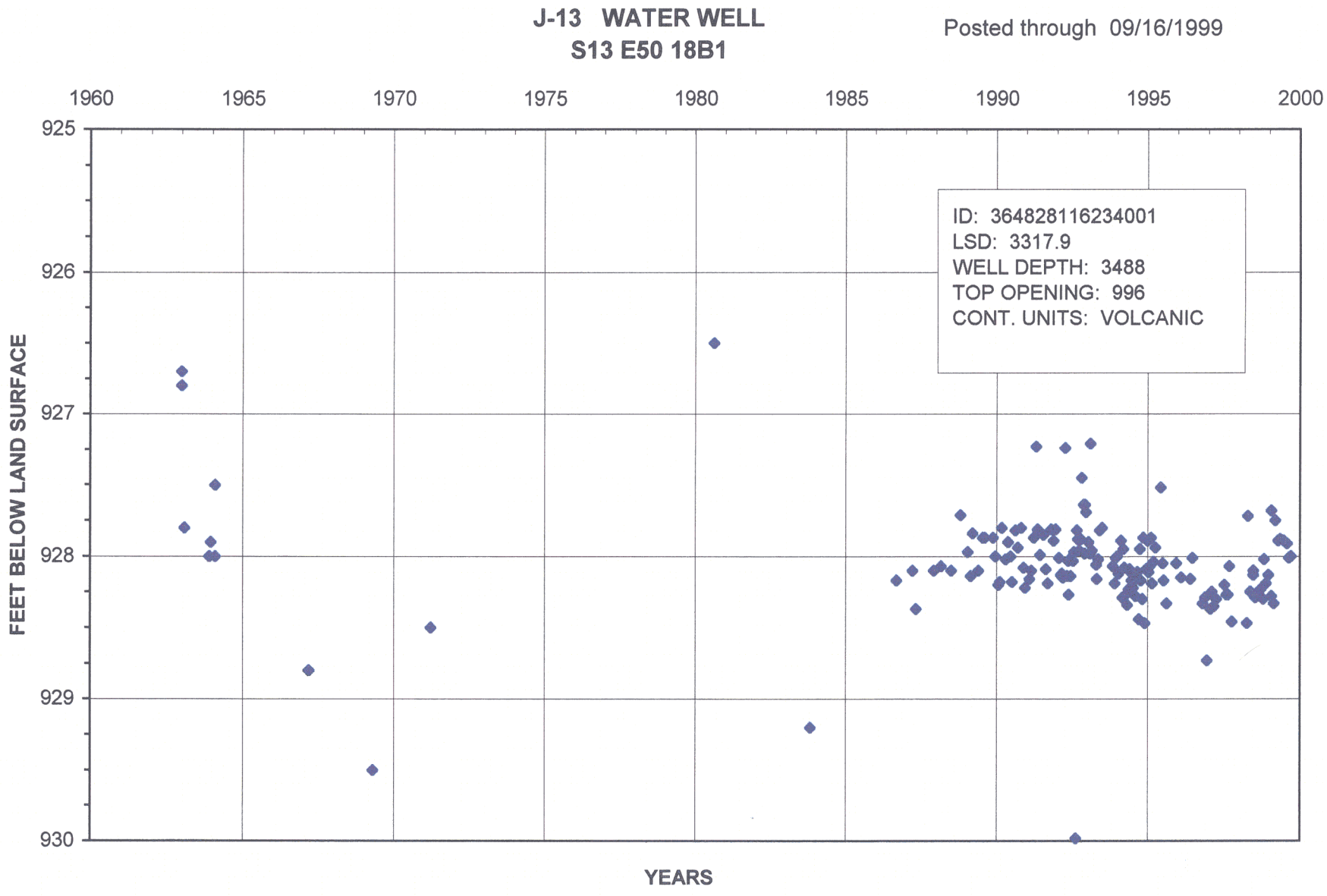


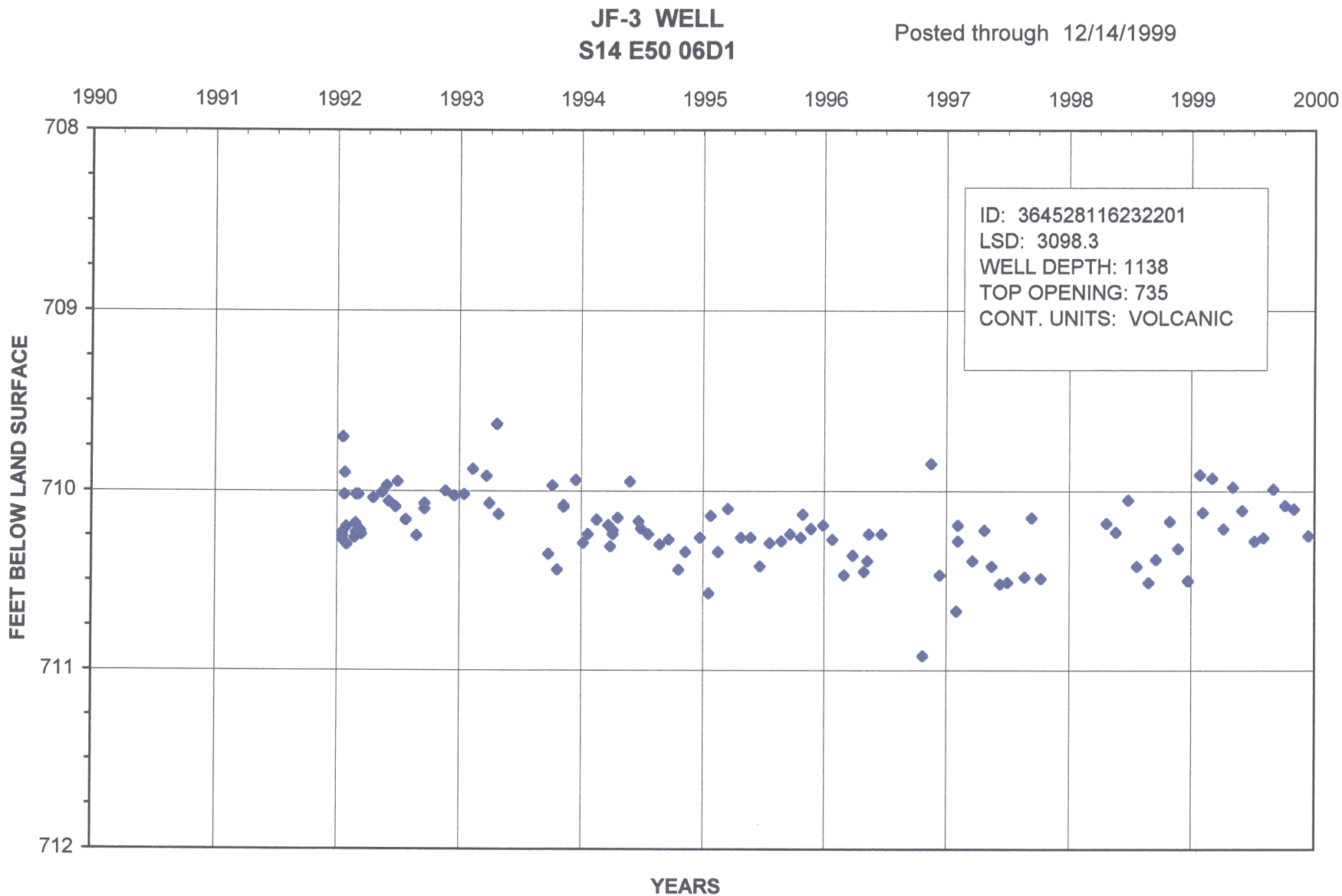
Hydrograph of well JF-2a



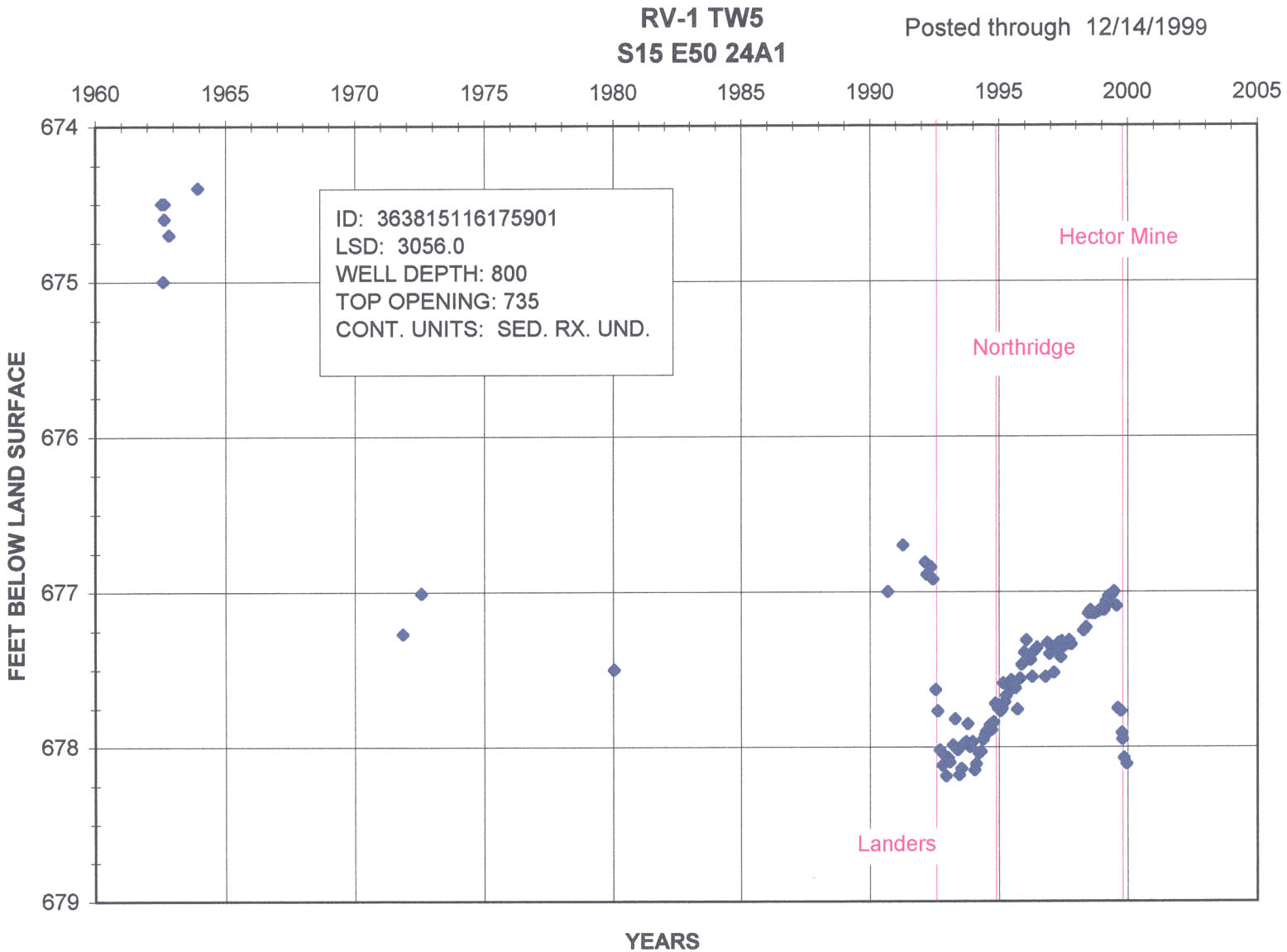
Hydrograph of well J-11


J-12 WATER WELL
S13 E51 31B1
Posted through 09/13/1999
1970
1975
1980
1985
1990
1995
2000
738
739
740
741
742
743
FEET BELOW LAND SURFACE
YEARS
ID: 364554116232401
LSD: 3128.4
WELL DEPTH: 1139
TOP OPENING: 793
CONT. UNITS: VOLCANIC

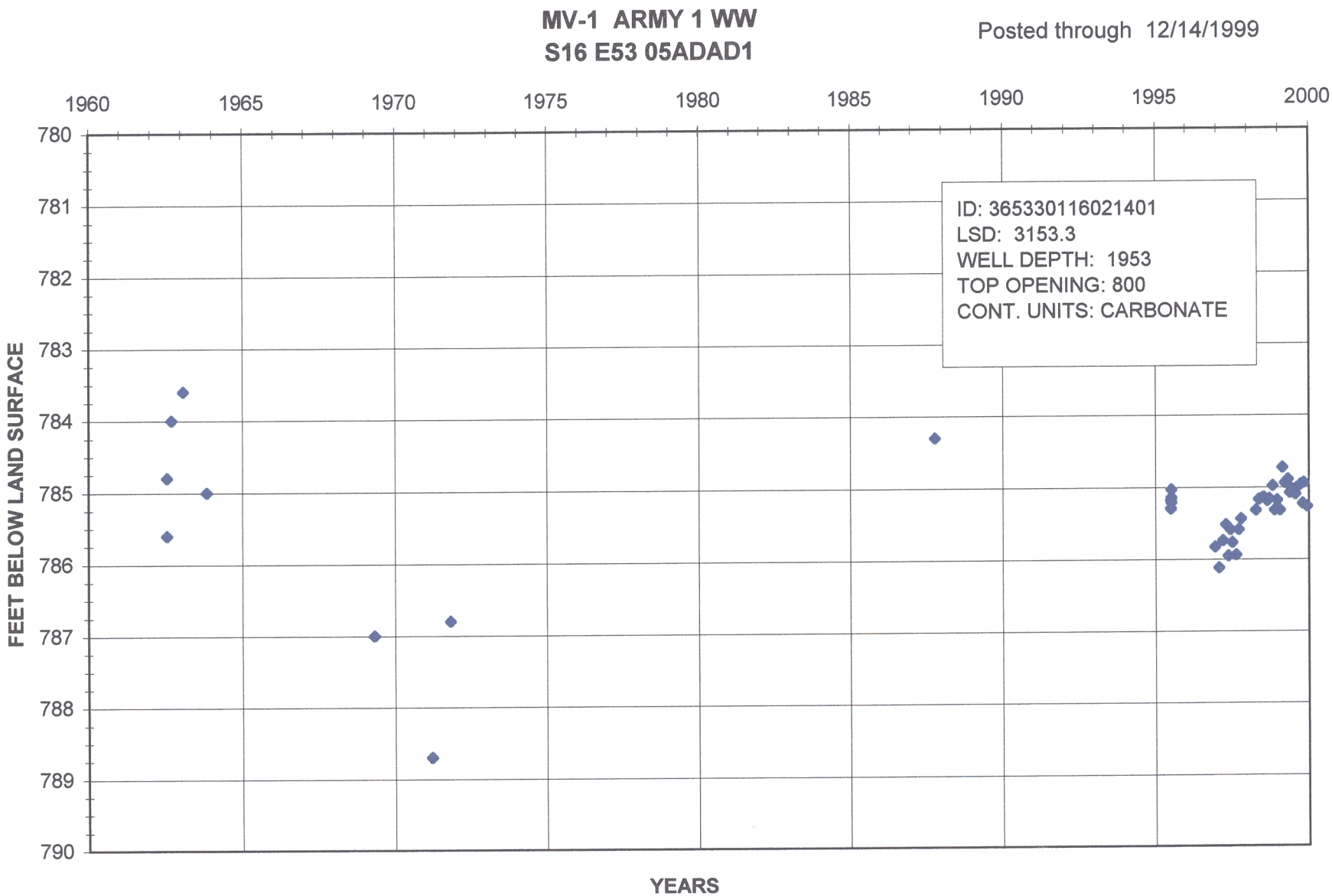

J-13 WATER WELL
S13 E50 18B1
Posted through 09/16/1999
1960
1965
1970
1975
1980
1985
1990
1995
2000
925
926
927
928
929
930
FEET BELOW LAND SURFACE
YEARS
ID: 364828116234001
LSD: 3317.9
WELL DEPTH: 3488
TOP OPENING: 996
CONT. UNITS: VOLCANIC



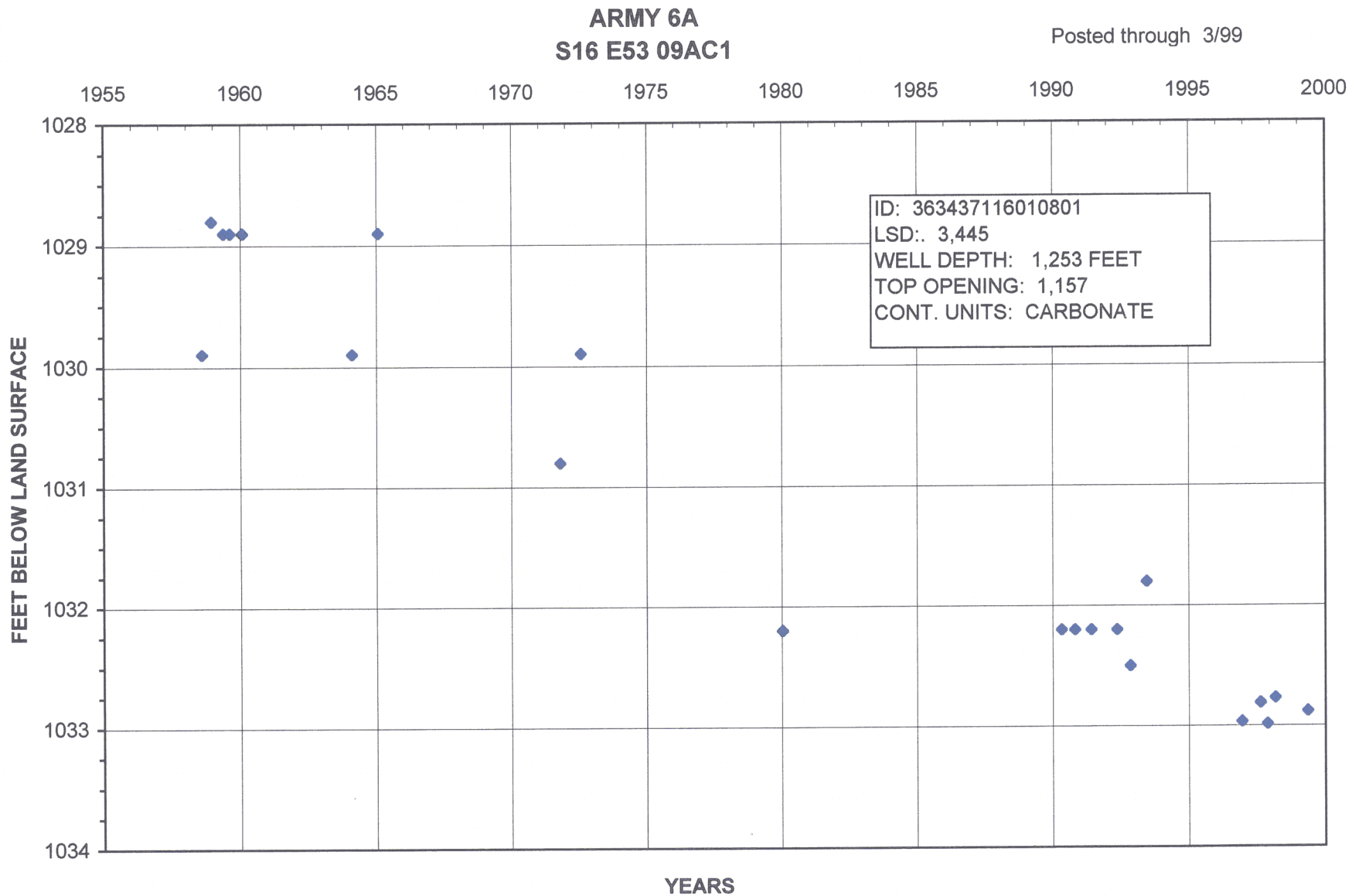
Hydrograph of well JF-3



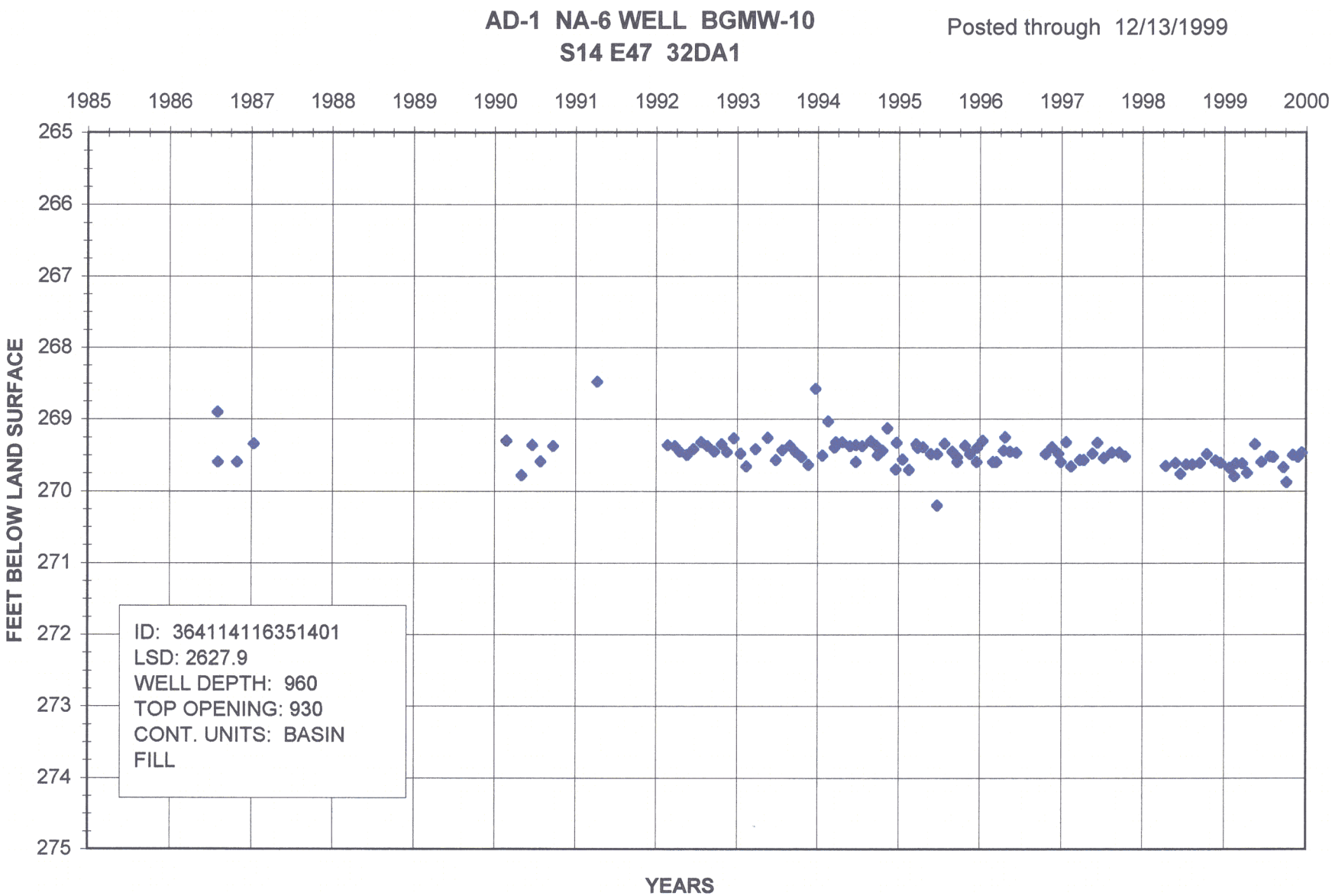
Hydrograph of well RV-1

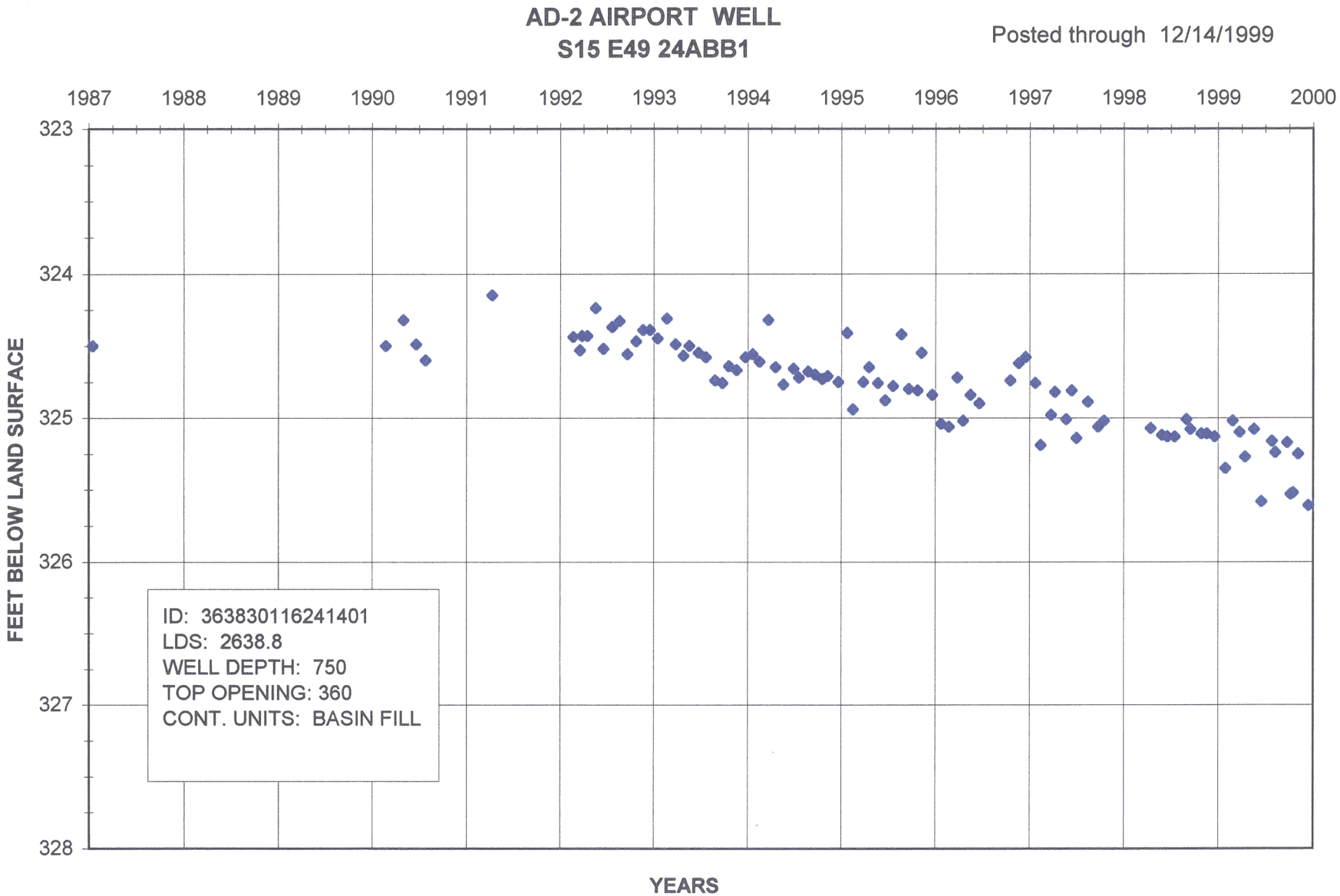


Hydrograph of well MV-1

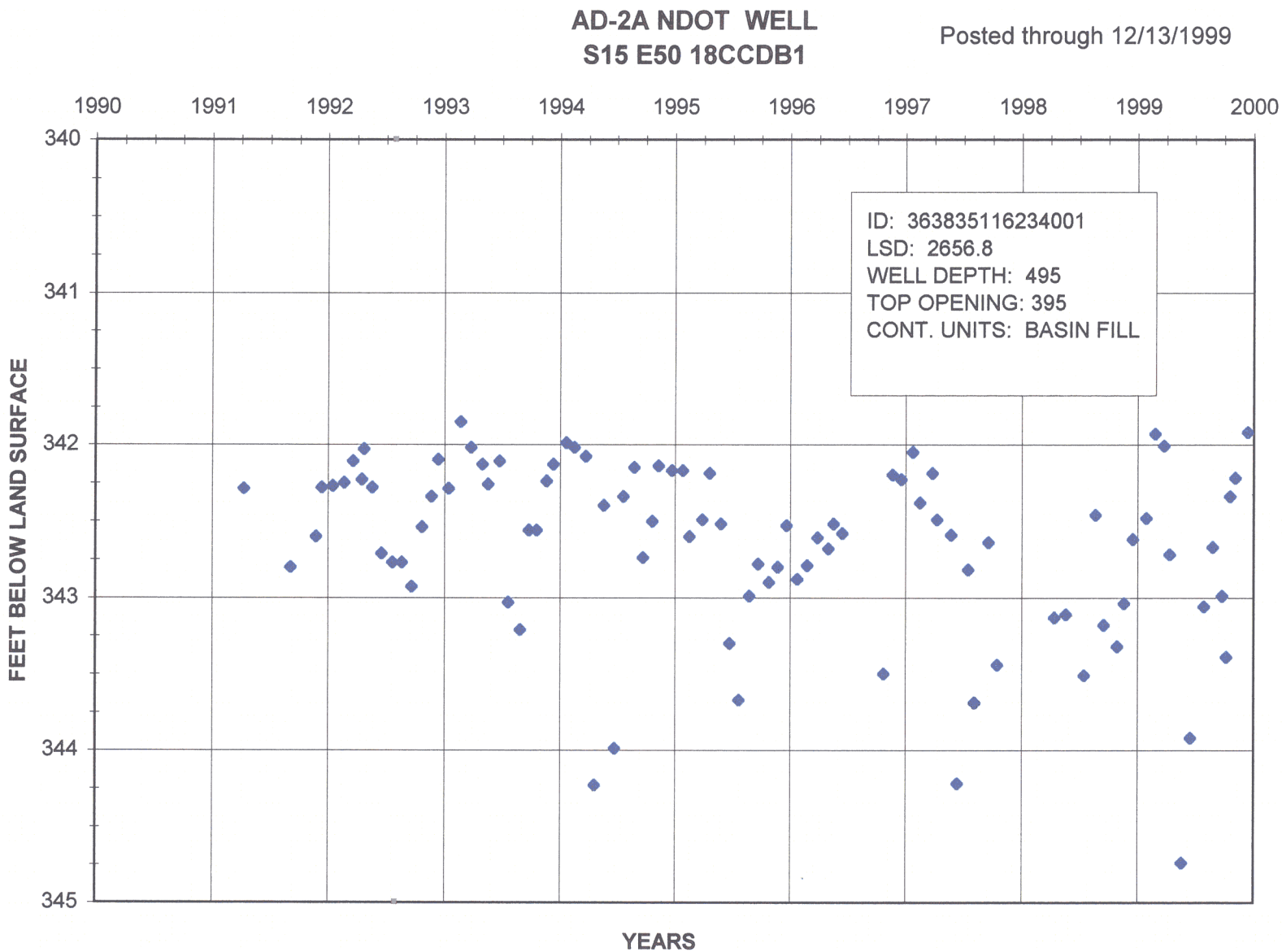


Hydrograph of well Army 6A

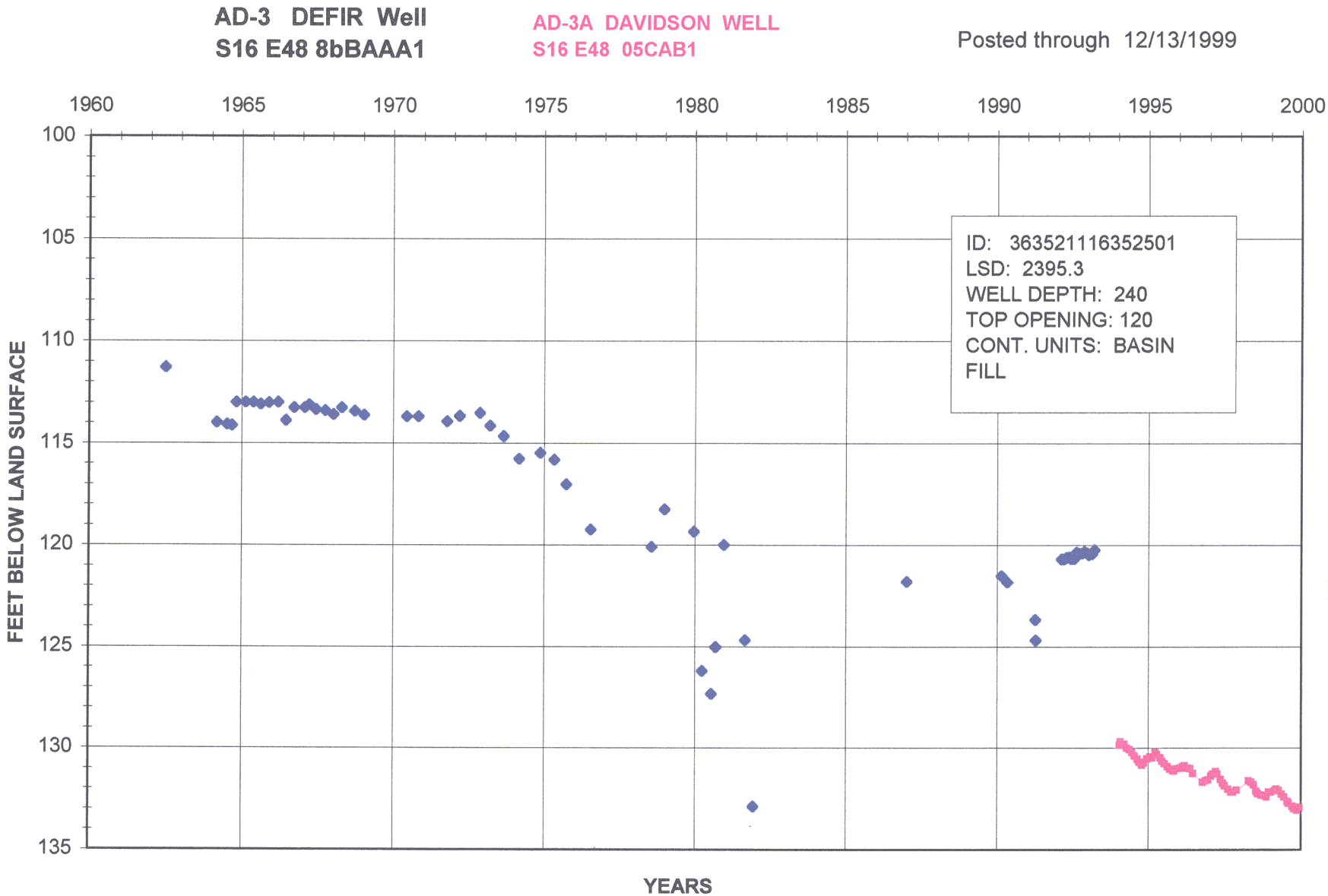

AD-1 NA-6 WELL BGMW-10
S14 E47 32DA1
Posted through 12/13/1999
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
265
266
267
268
269
270
271
272
273
274
275
FEET BELOW LAND SURFACE
YEARS
ID: 364114116351401
LSD: 2627.9
WELL DEPTH: 960
TOP OPENING: 930
CONT. UNITS: BASIN FILL



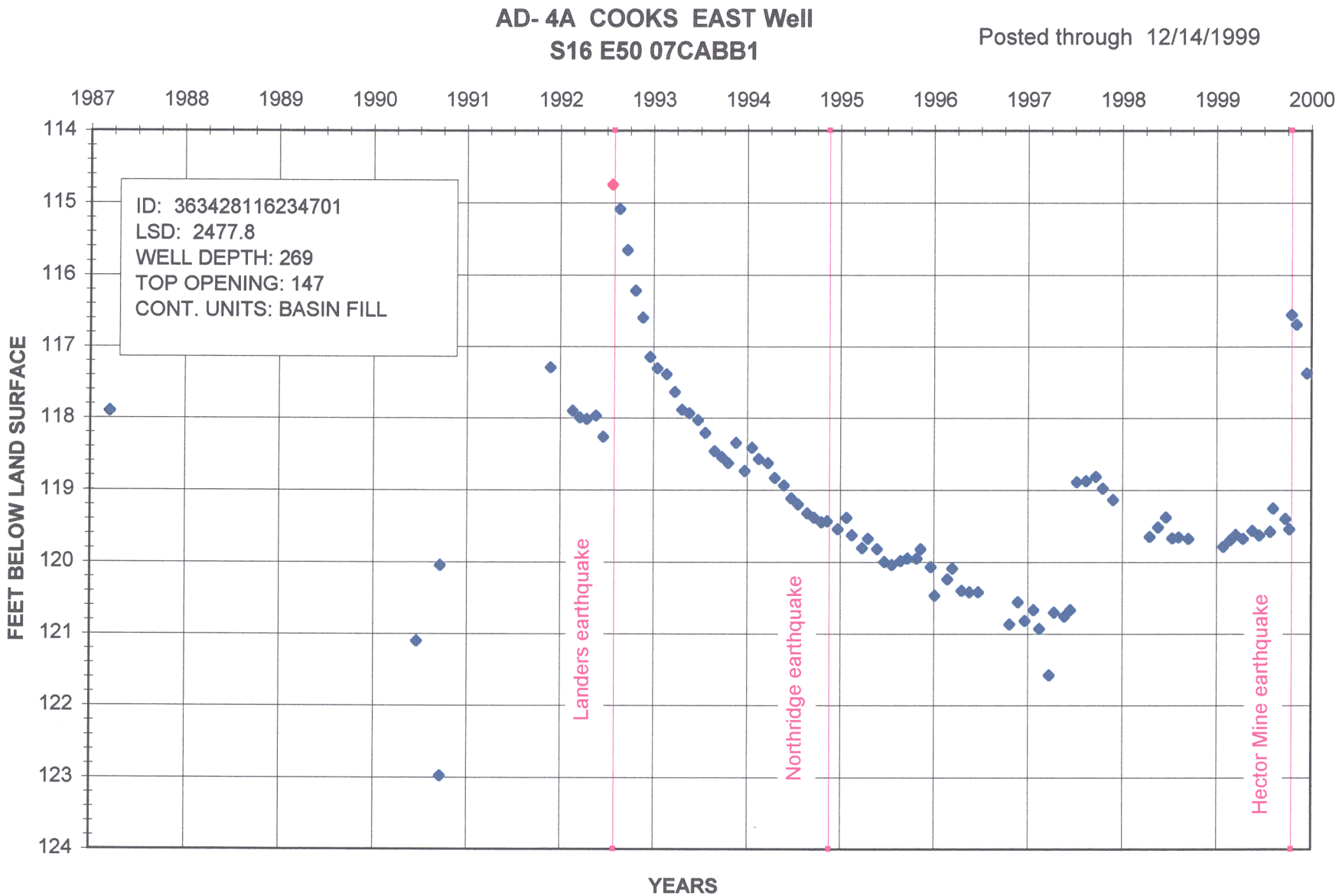
Hydrograph of well AD-2



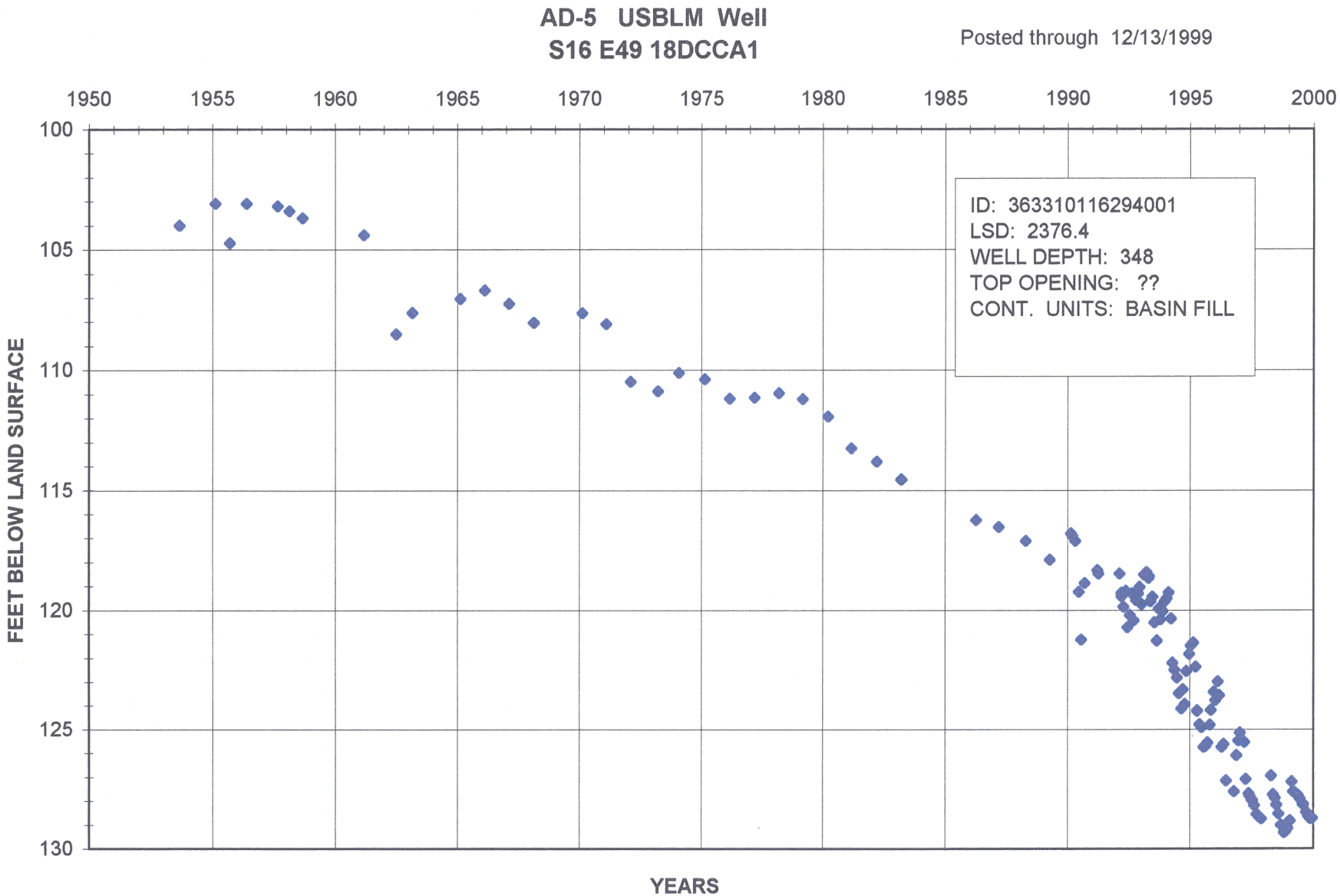
Hydrograph of well AD-2a



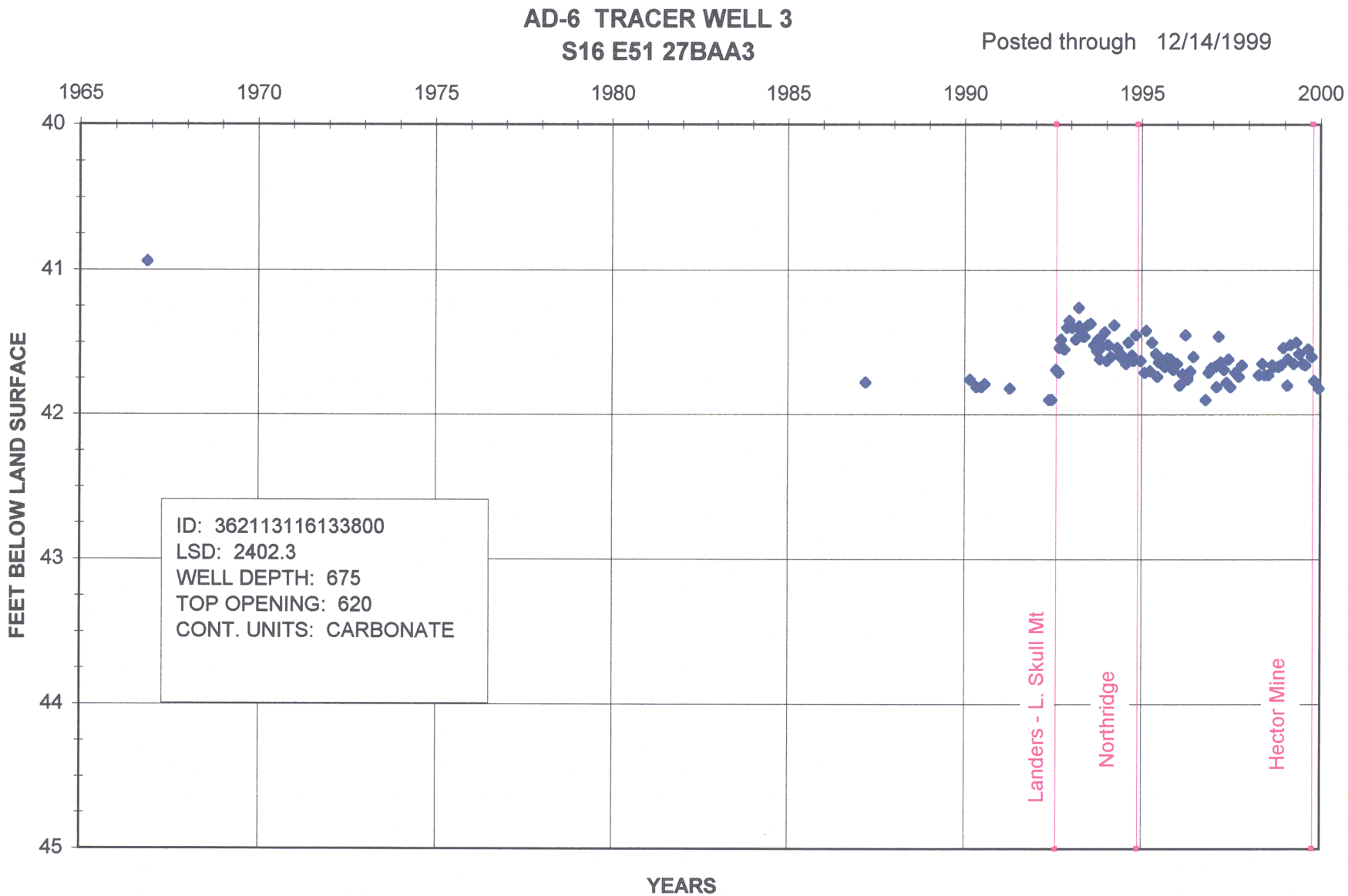
Hydrograph of wells AD-3 and AD-3a



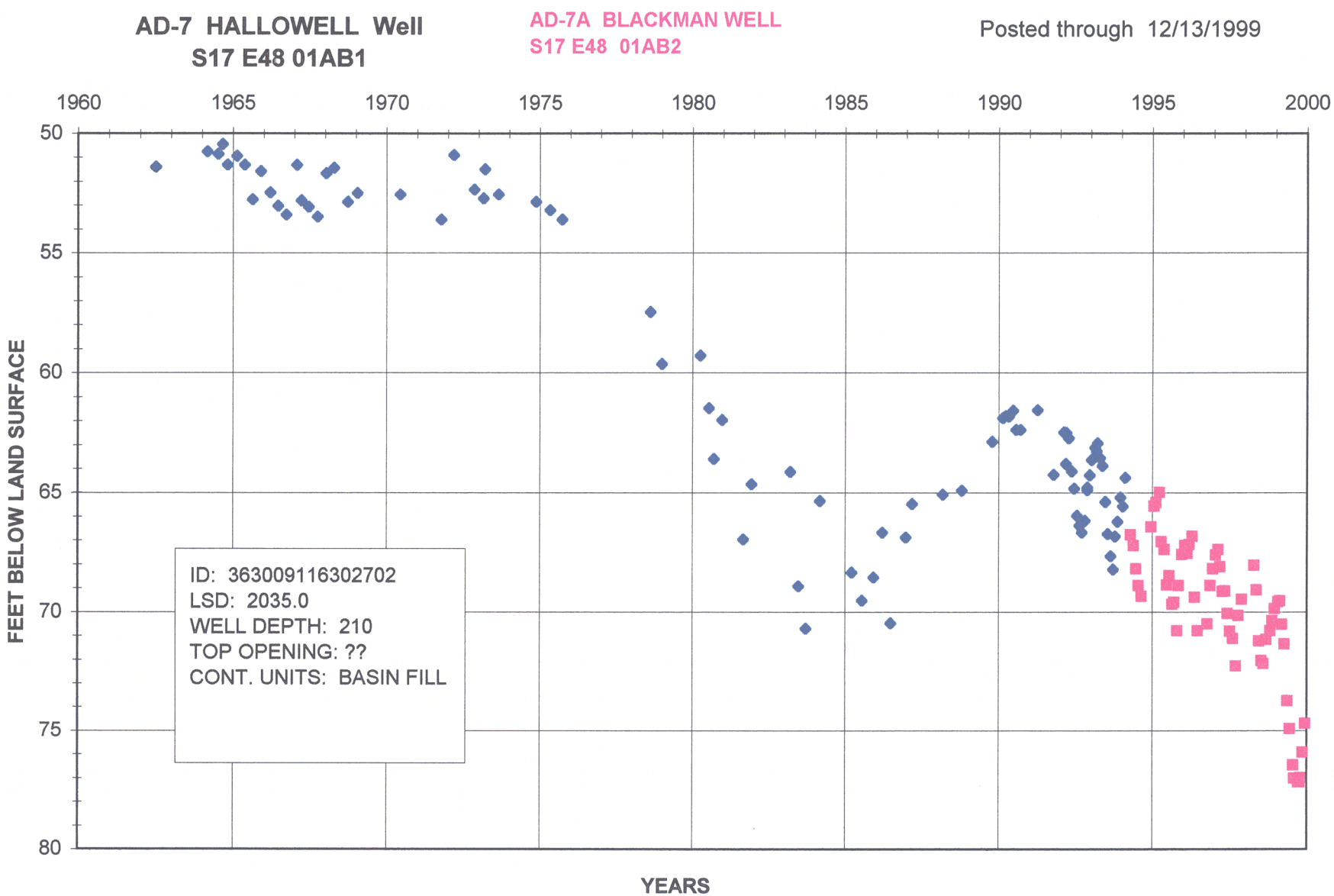
Hydrograph of well AD-4a



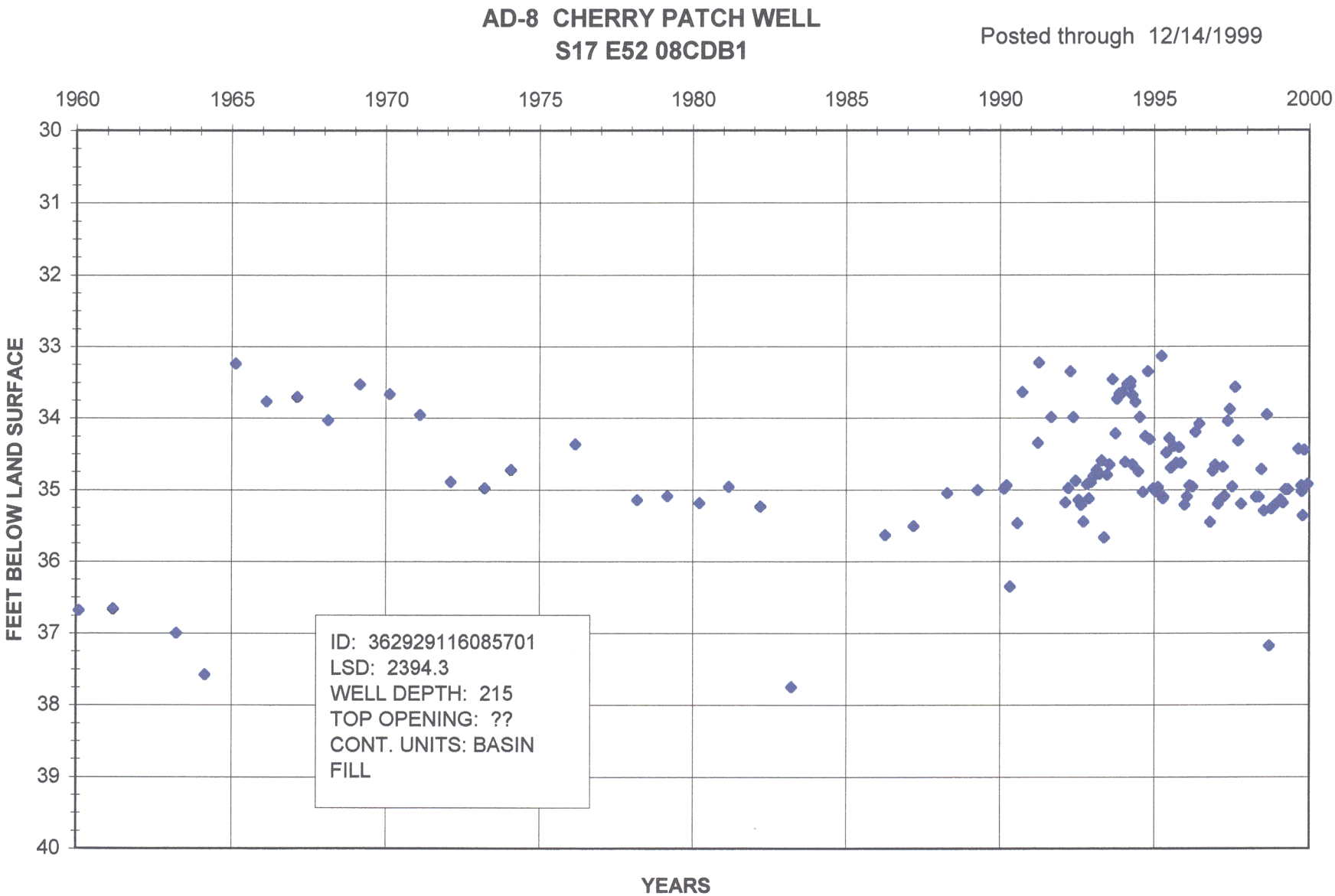
Hydrograph of well AD-5



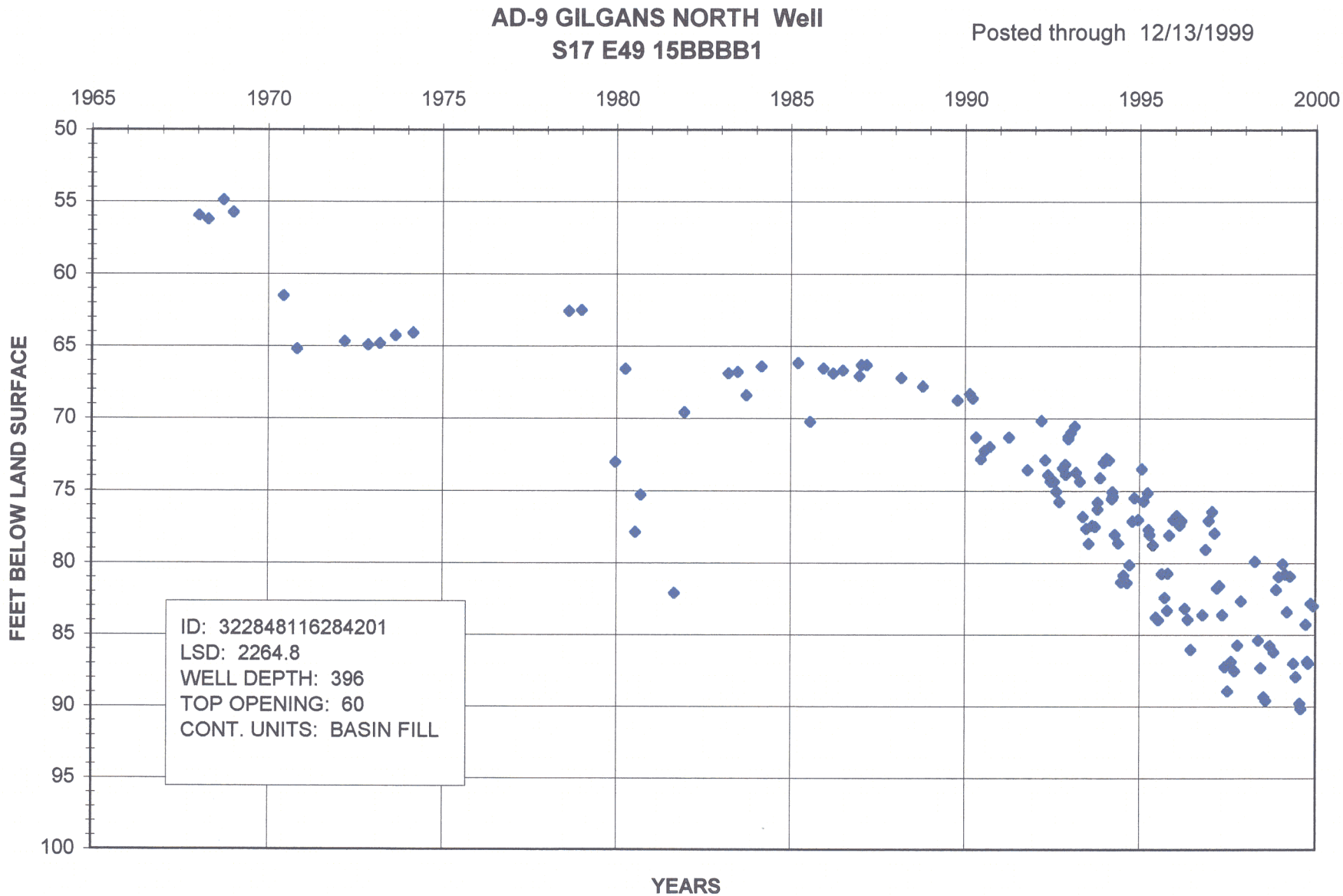
Hydrograph of well AD-6



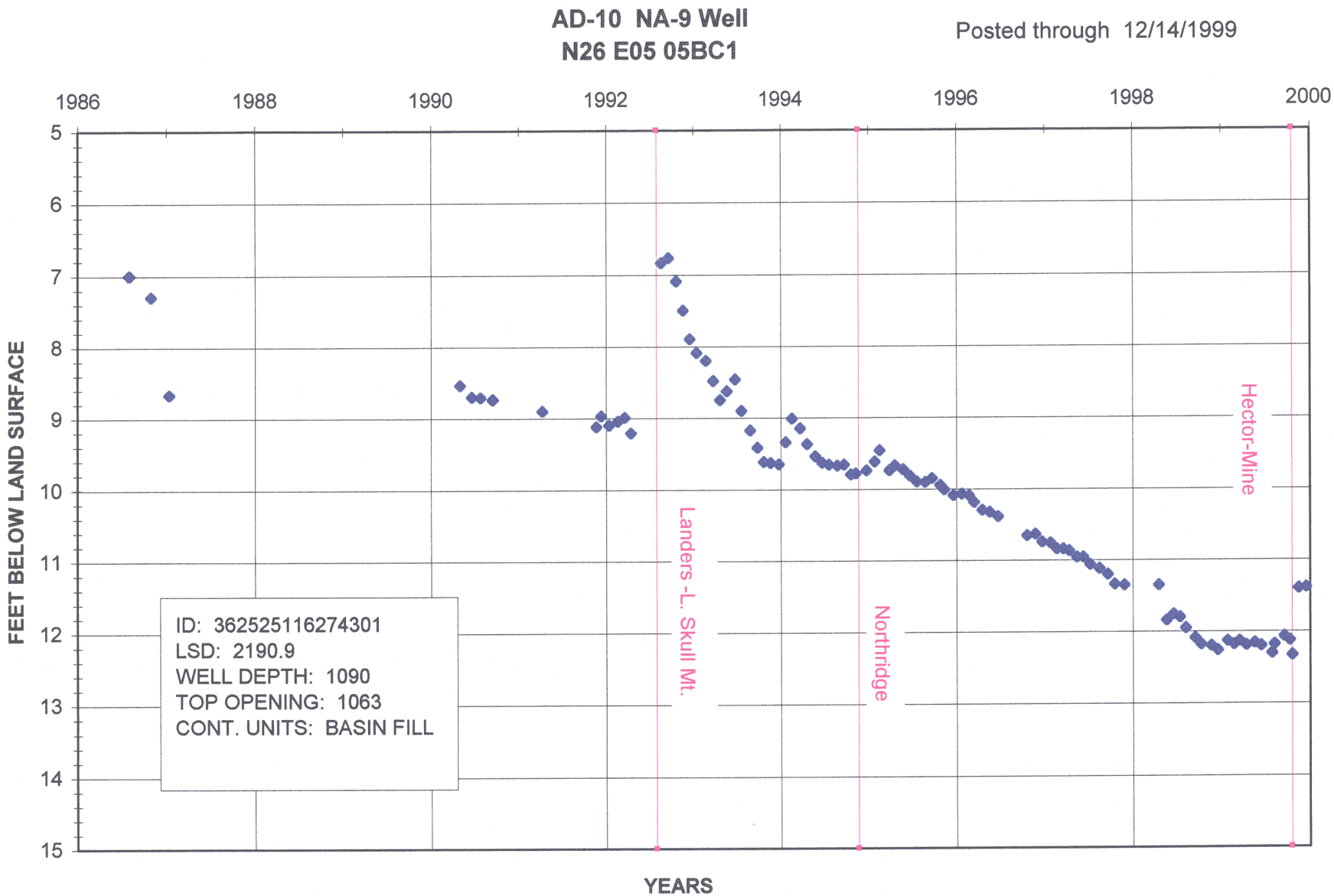
Hydrograph of wells AD-7 and AD-7a



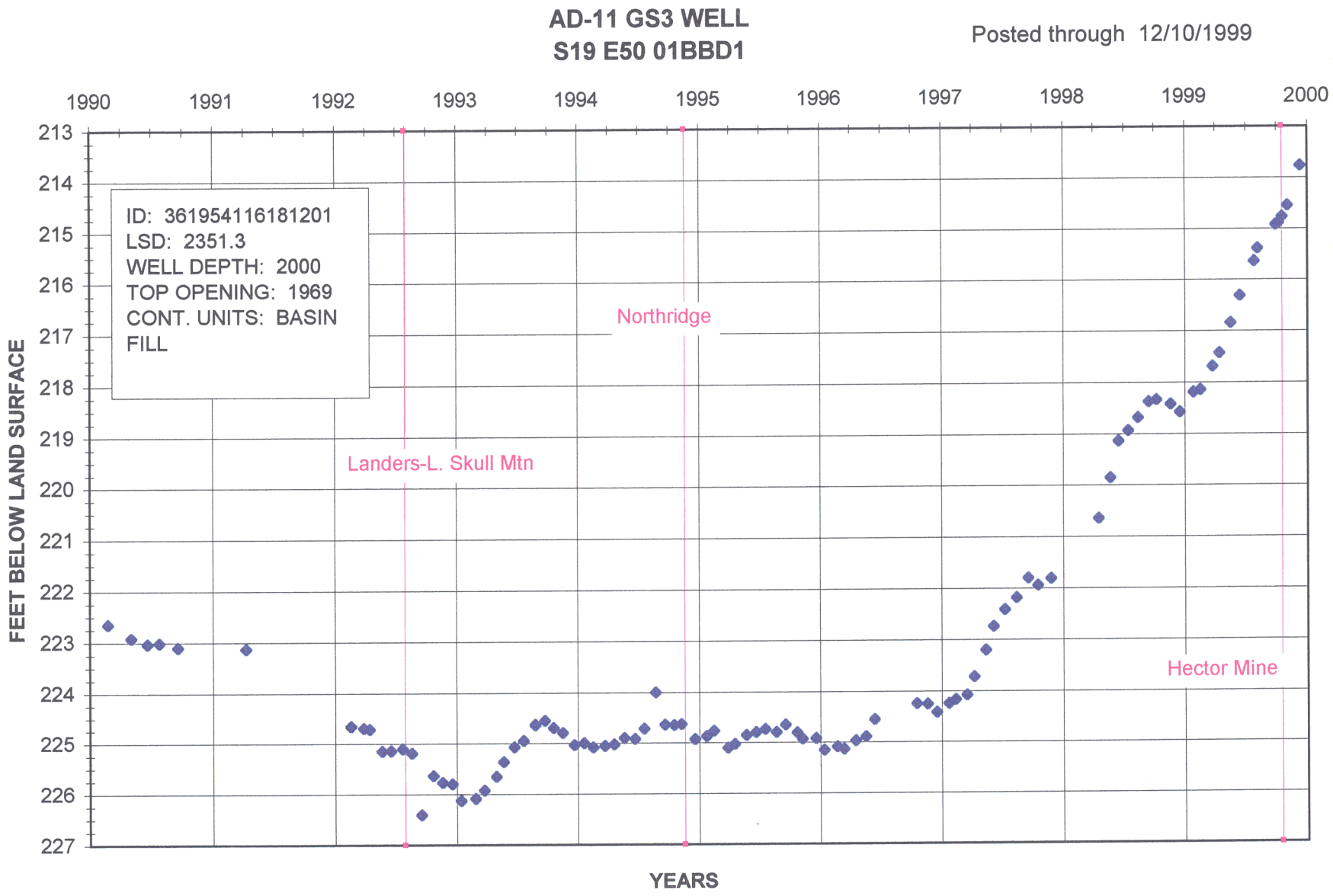
Hydrograph of well AD-8



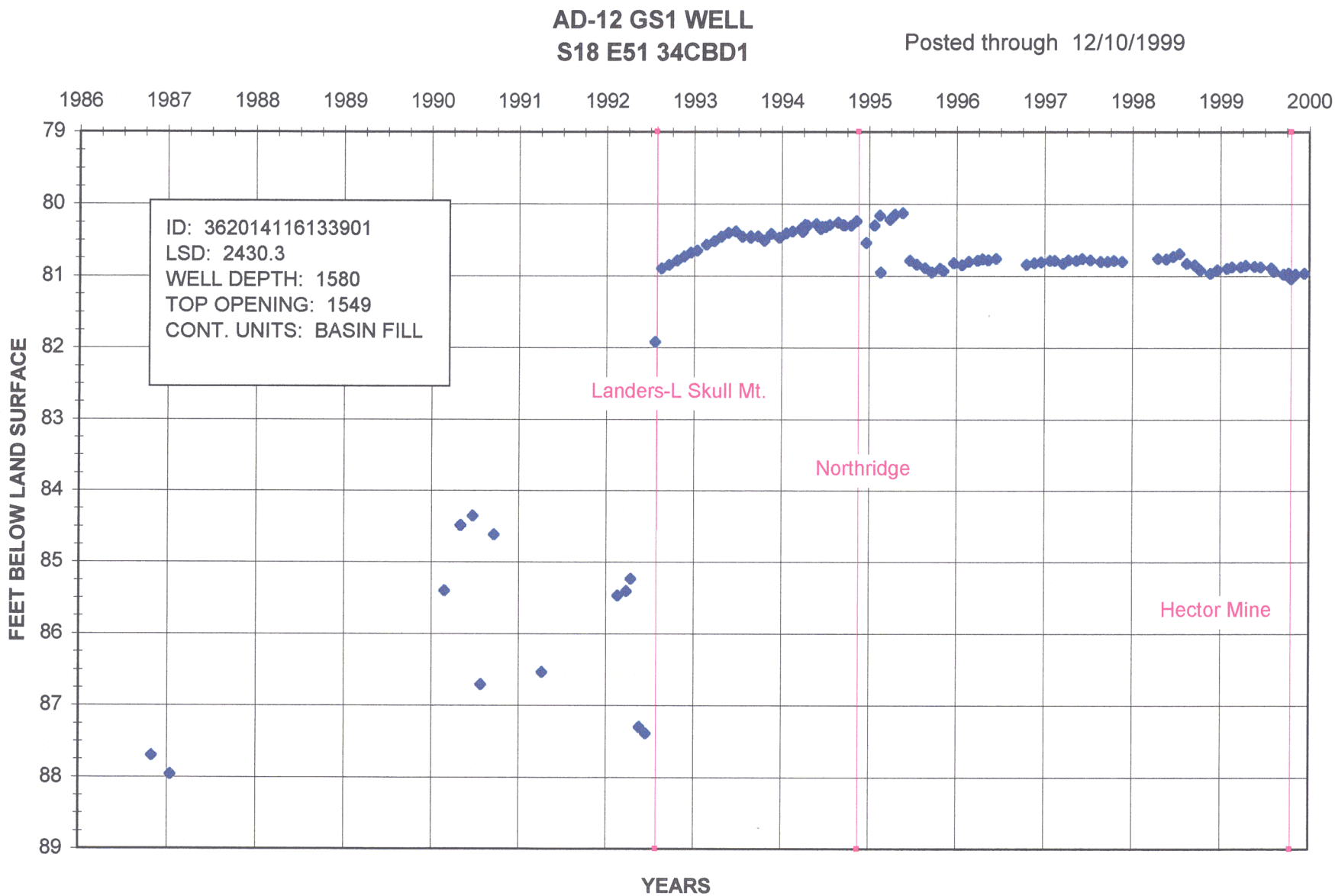
Hydrograph of well AD-9



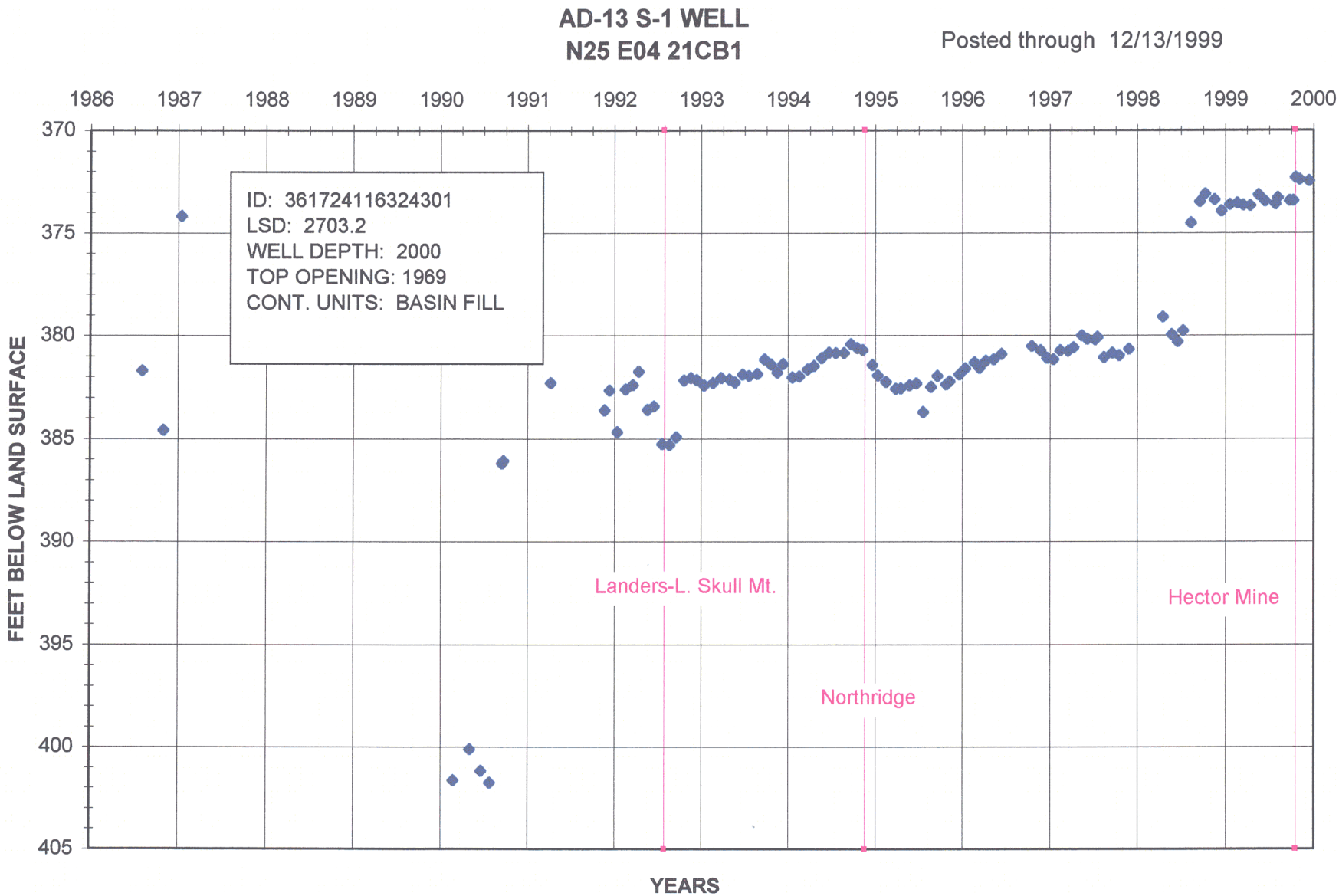
Hydrograph of well AD-10



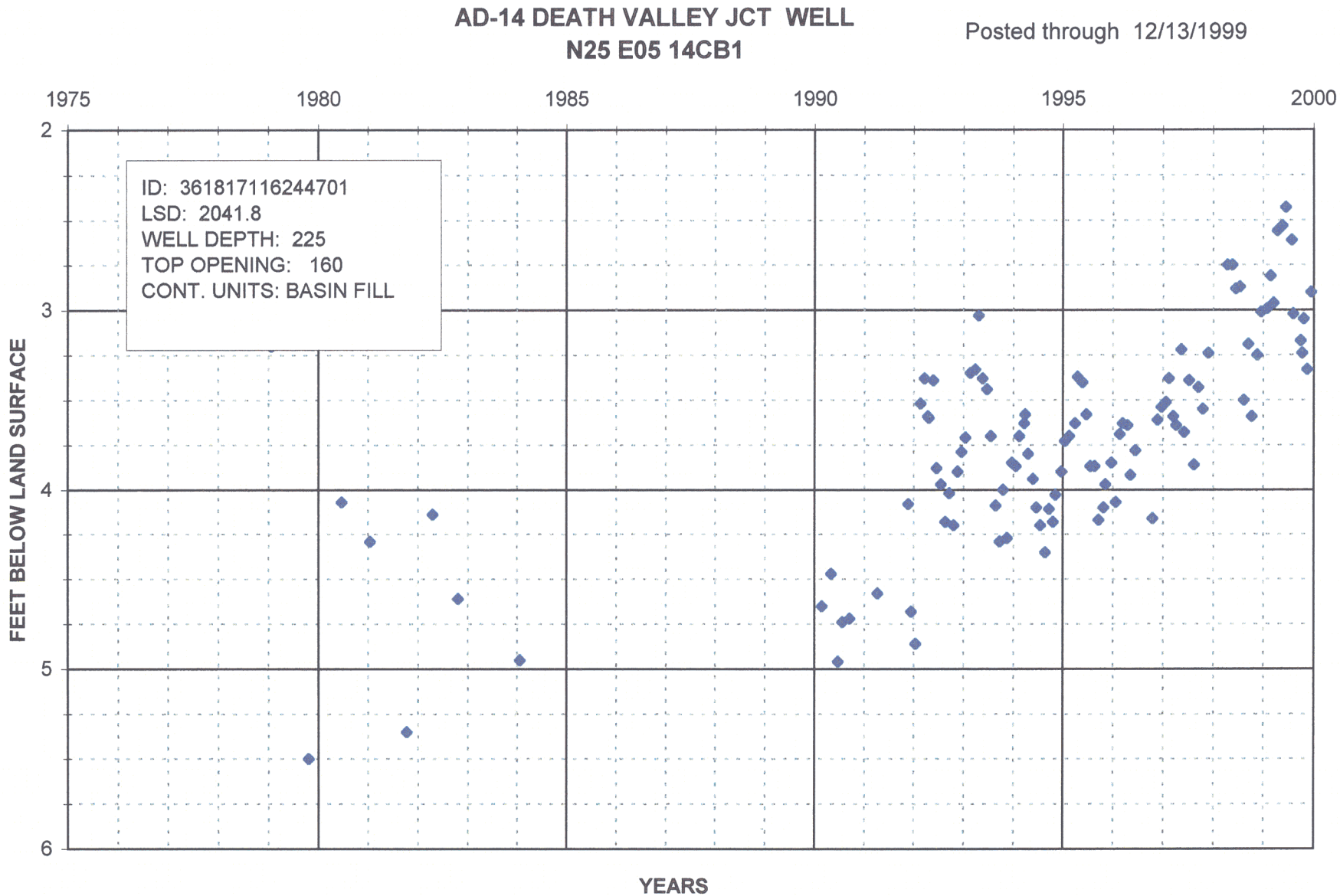
Hydrograph of well AD-11



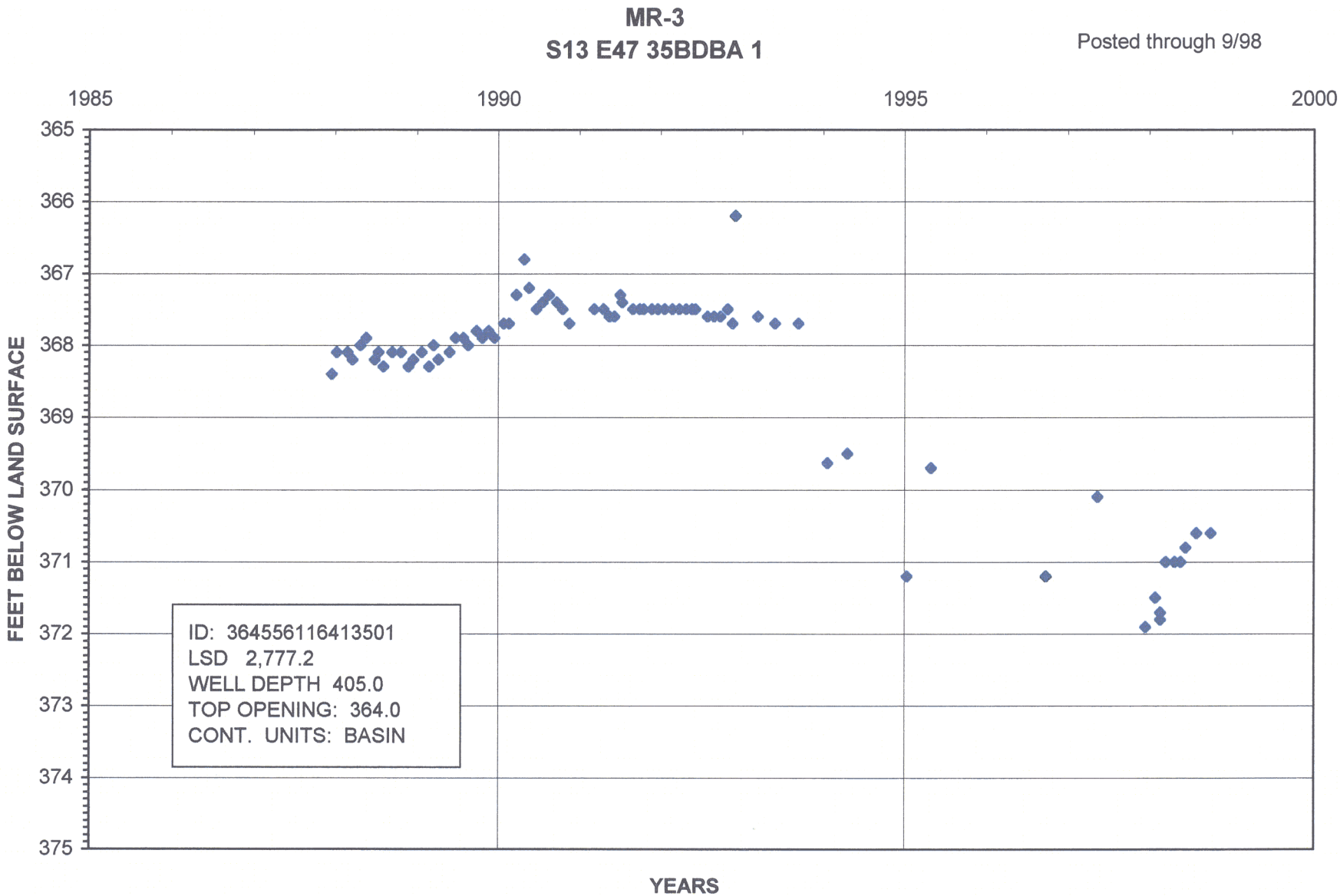
Hydrograph of well AD-12



Hydrograph of well AD-13



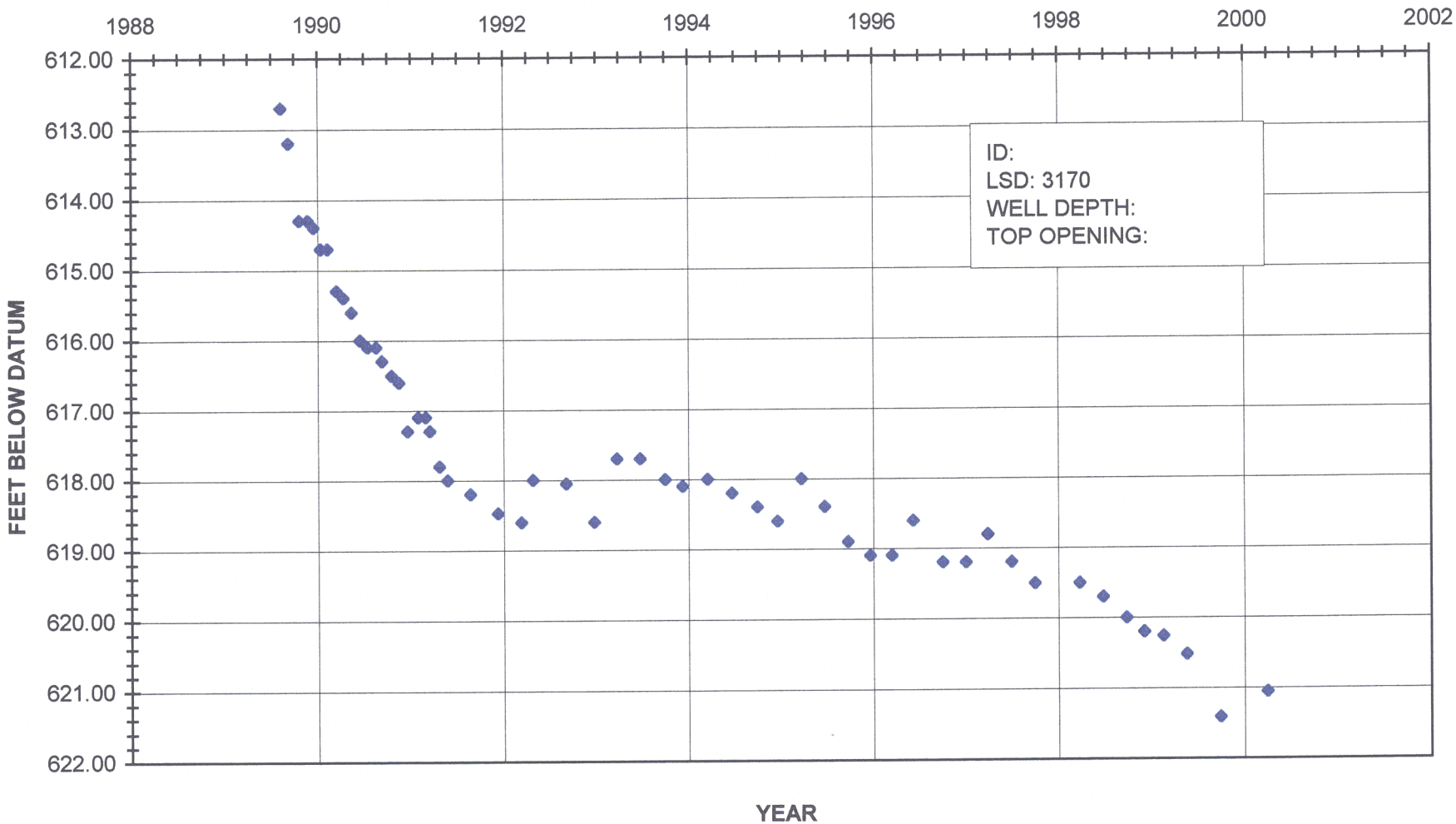
Hydrograph of well AD-14



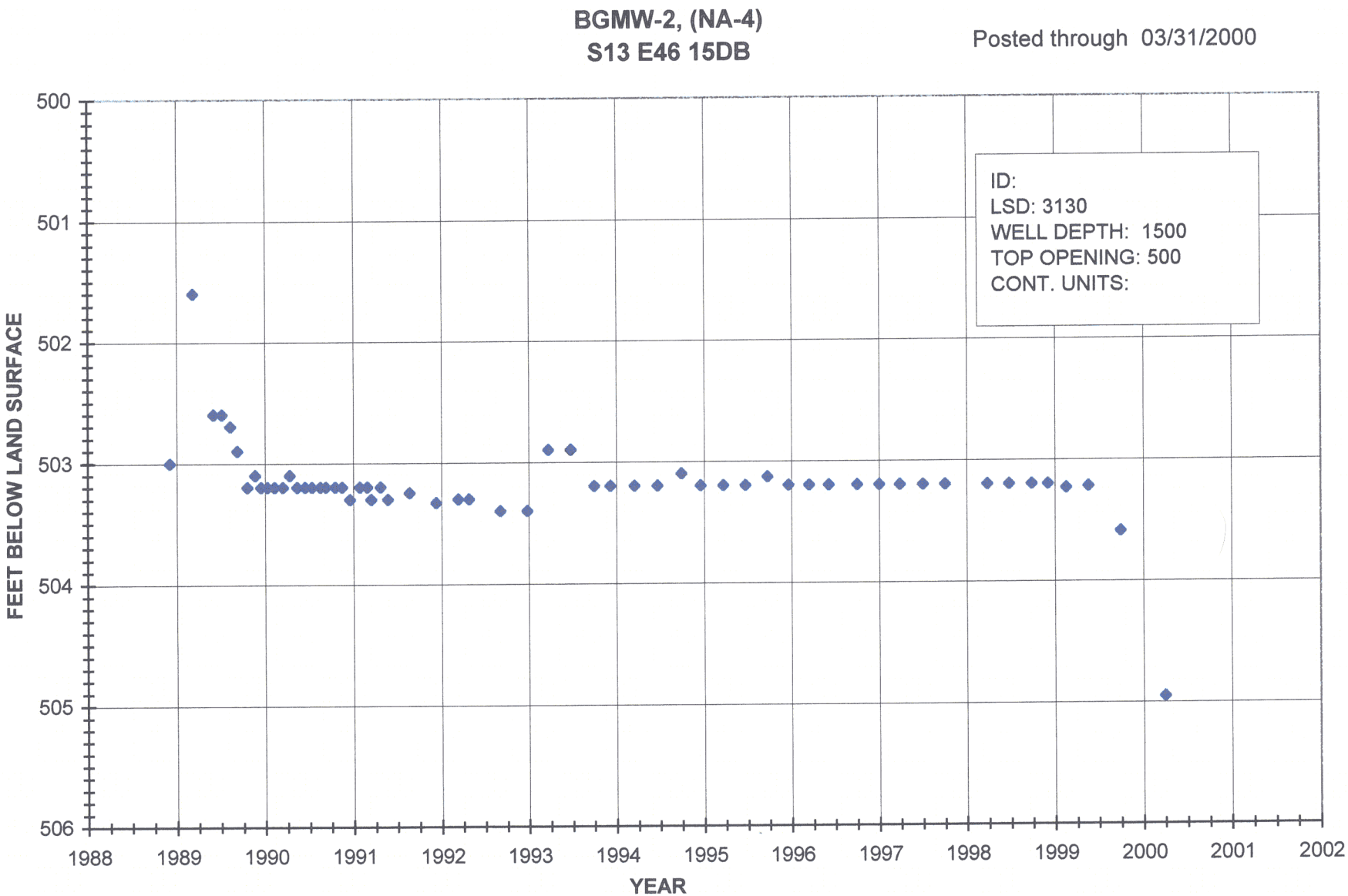
Hydrogaph of well MR-3

BGMW-1
S13 E46 10DB

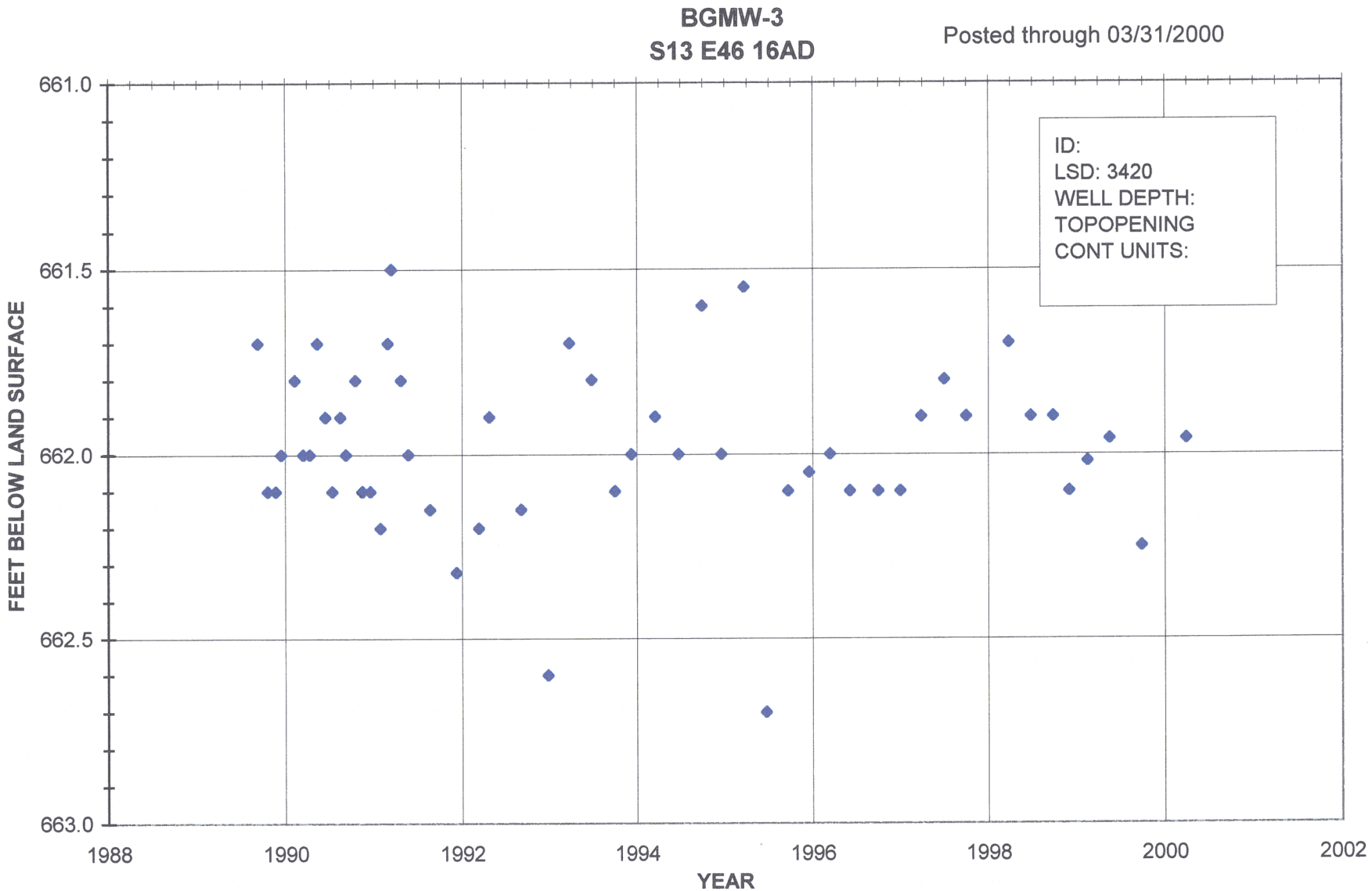
POSTED TO 03/31/2000



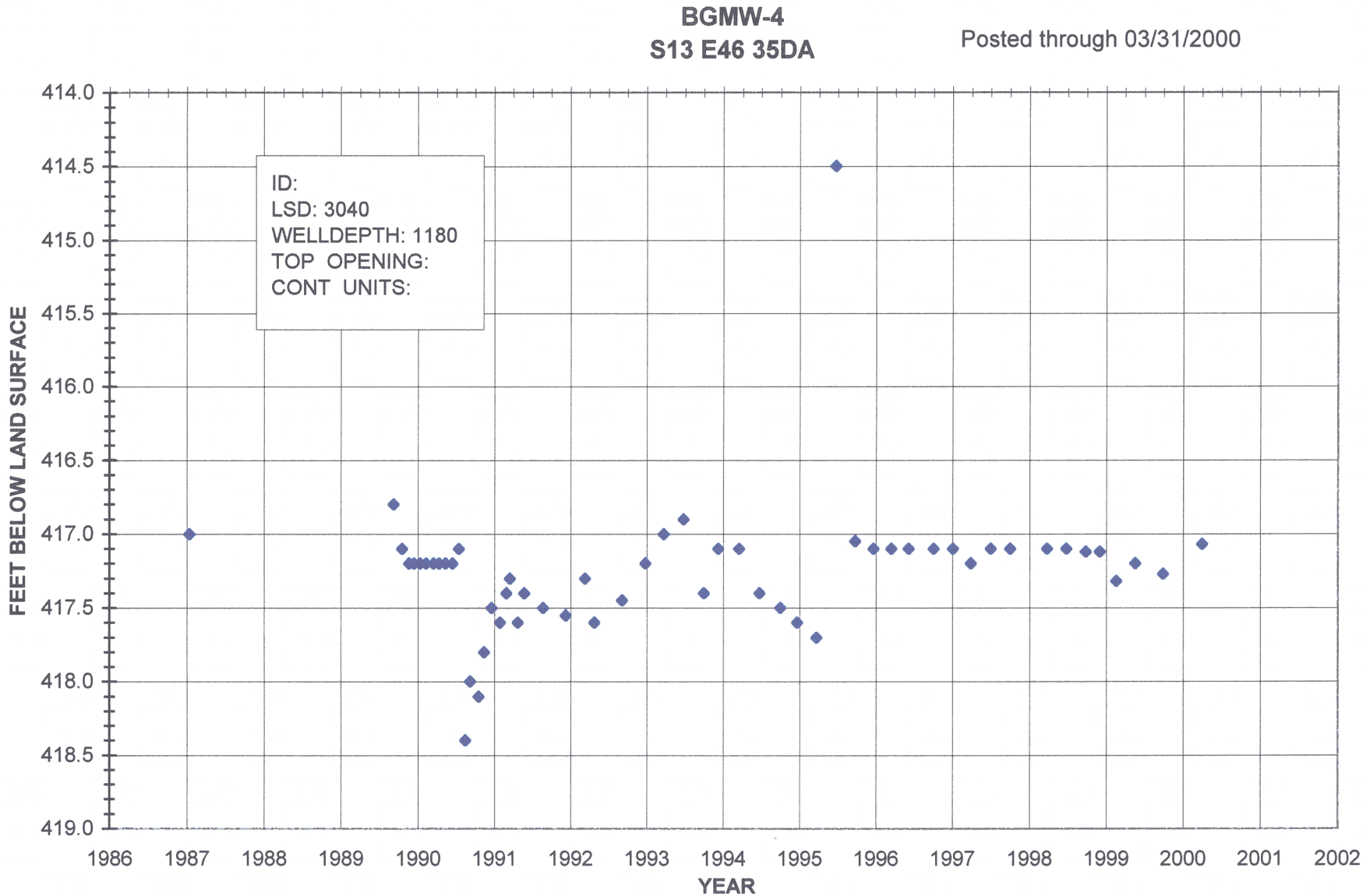
Hydrogaph of well MW-1

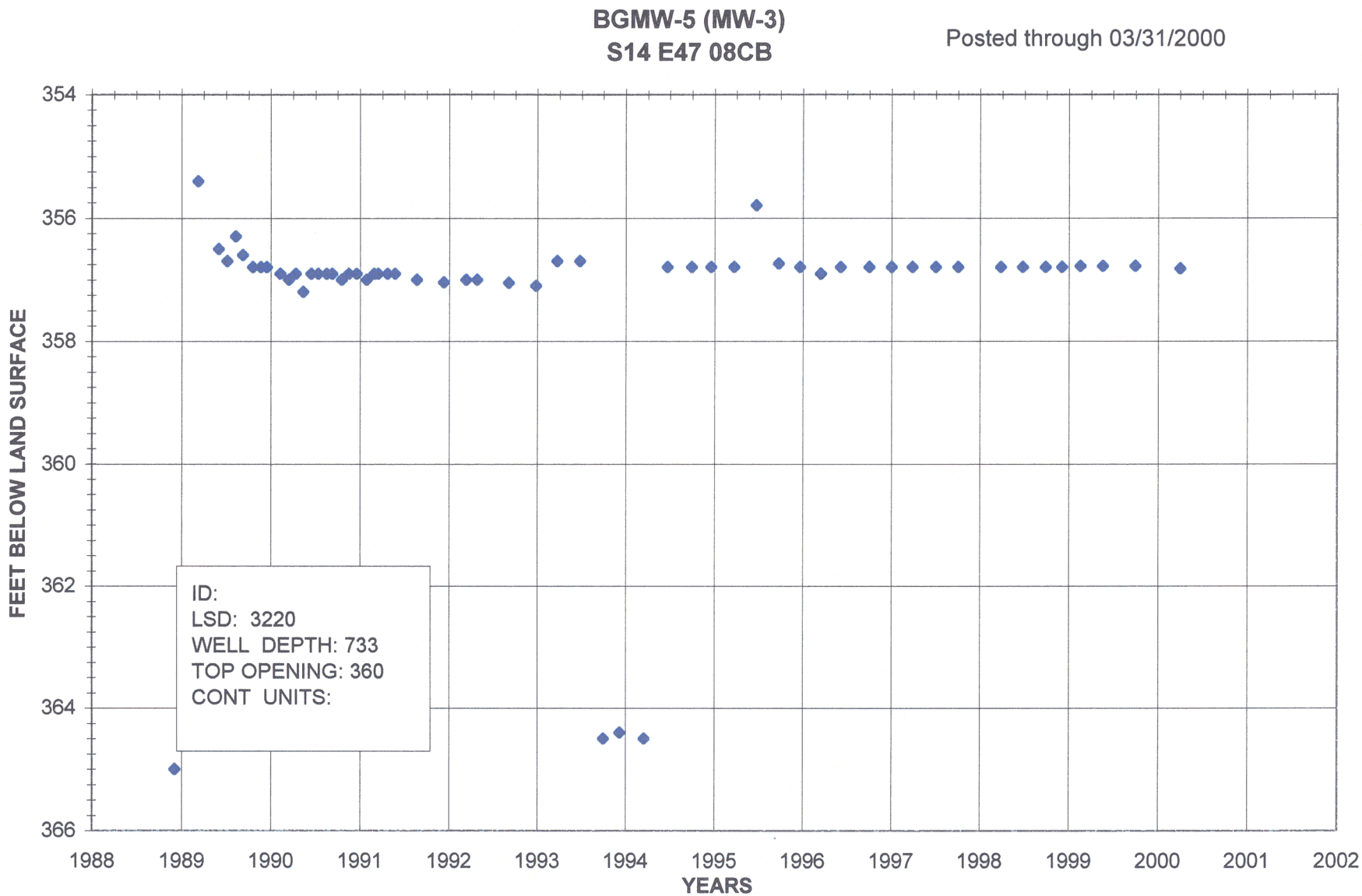


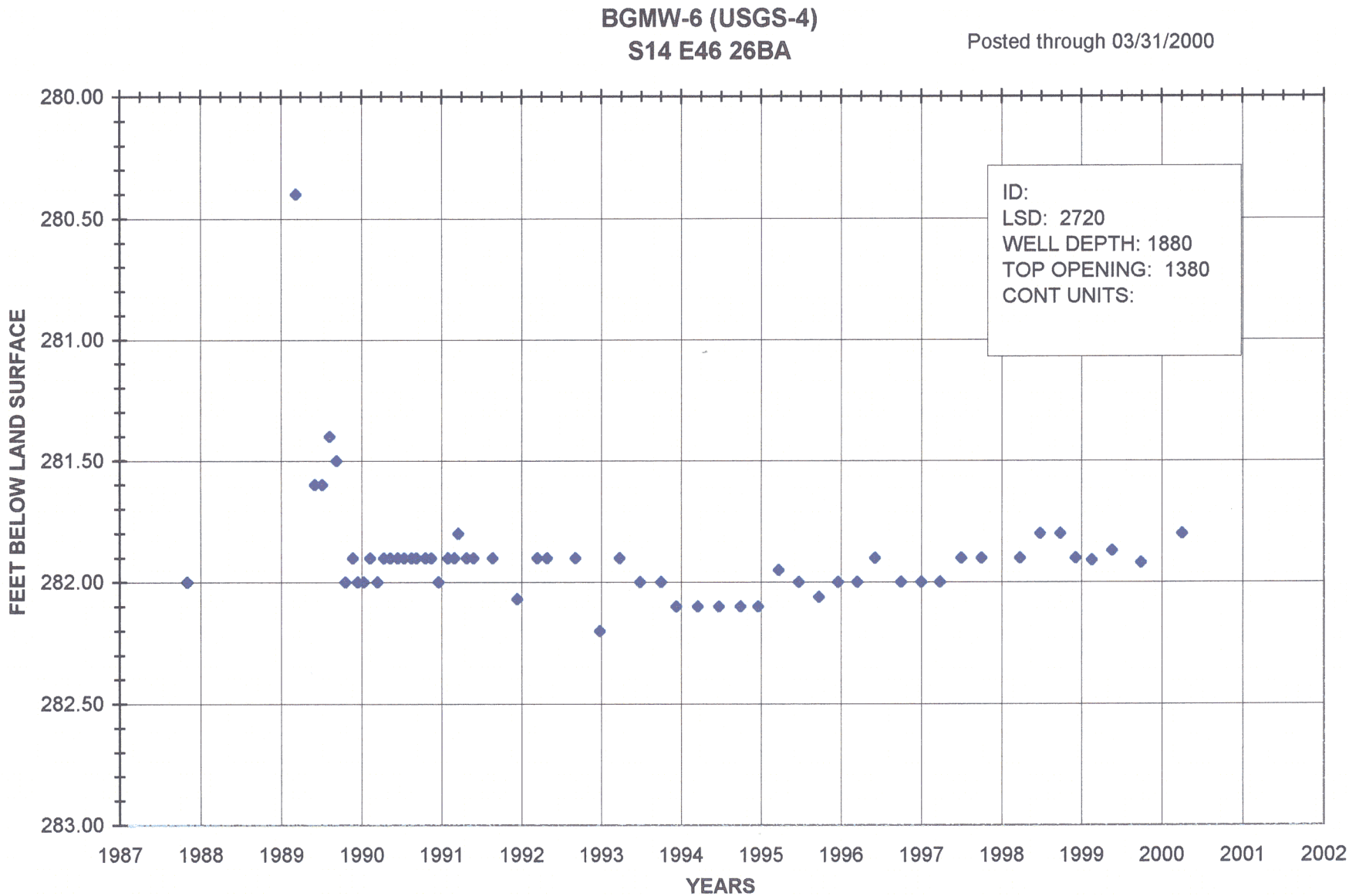
Hydrograph of well MW-2



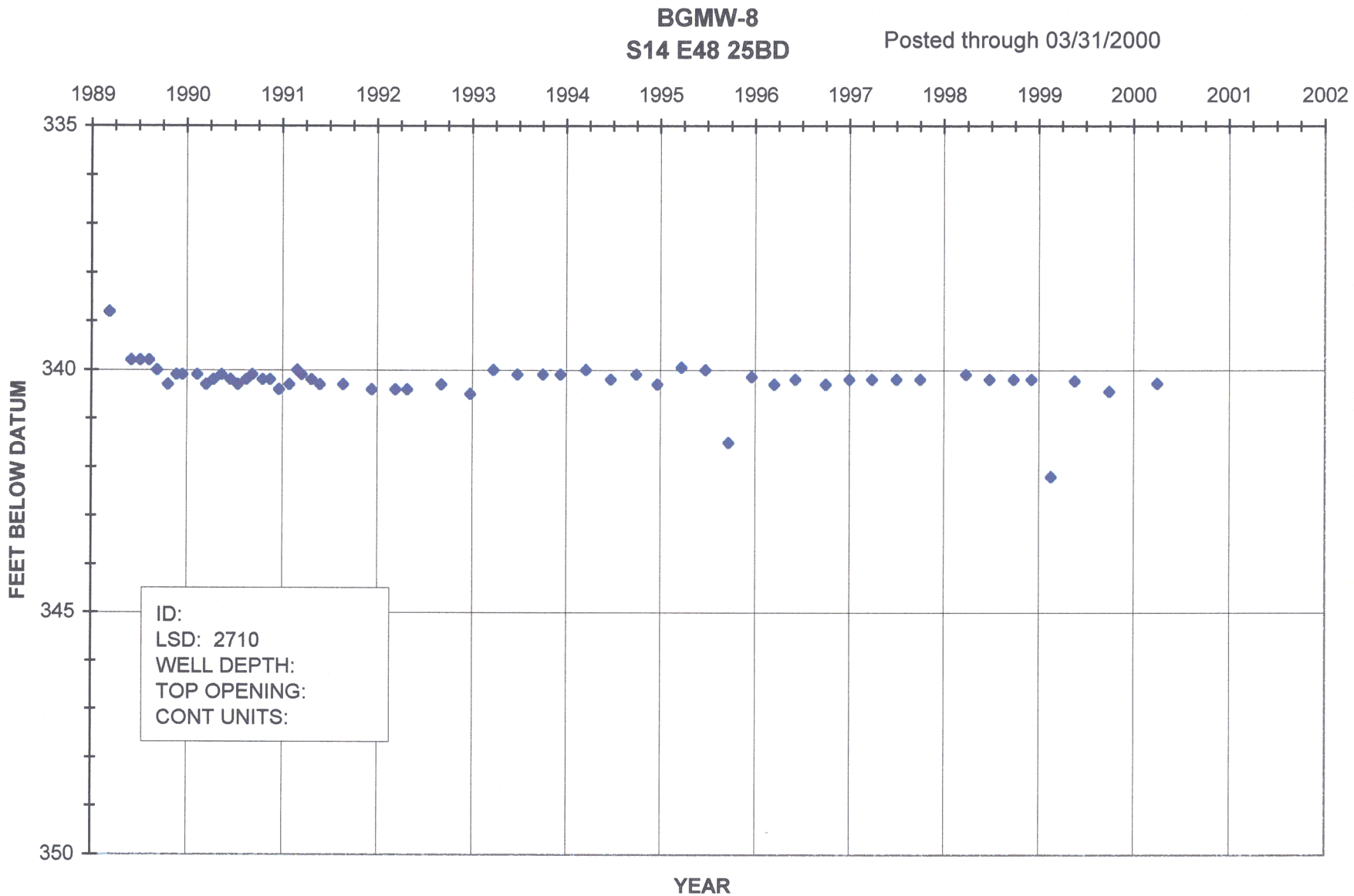
Hydrograph of well MW-3


BGMW-4
S13 E46 35DA
Posted through 03/31/2000
ID:
LSD: 3040
WELLDEPTH: 1180
TOP OPENING:
CONT UNITS:
FEET BELOW LAND SURFACE
414.0
414.5
415.0
415.5
416.0
416.5
417.0
417.5
418.0
418.5
419.0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEAR

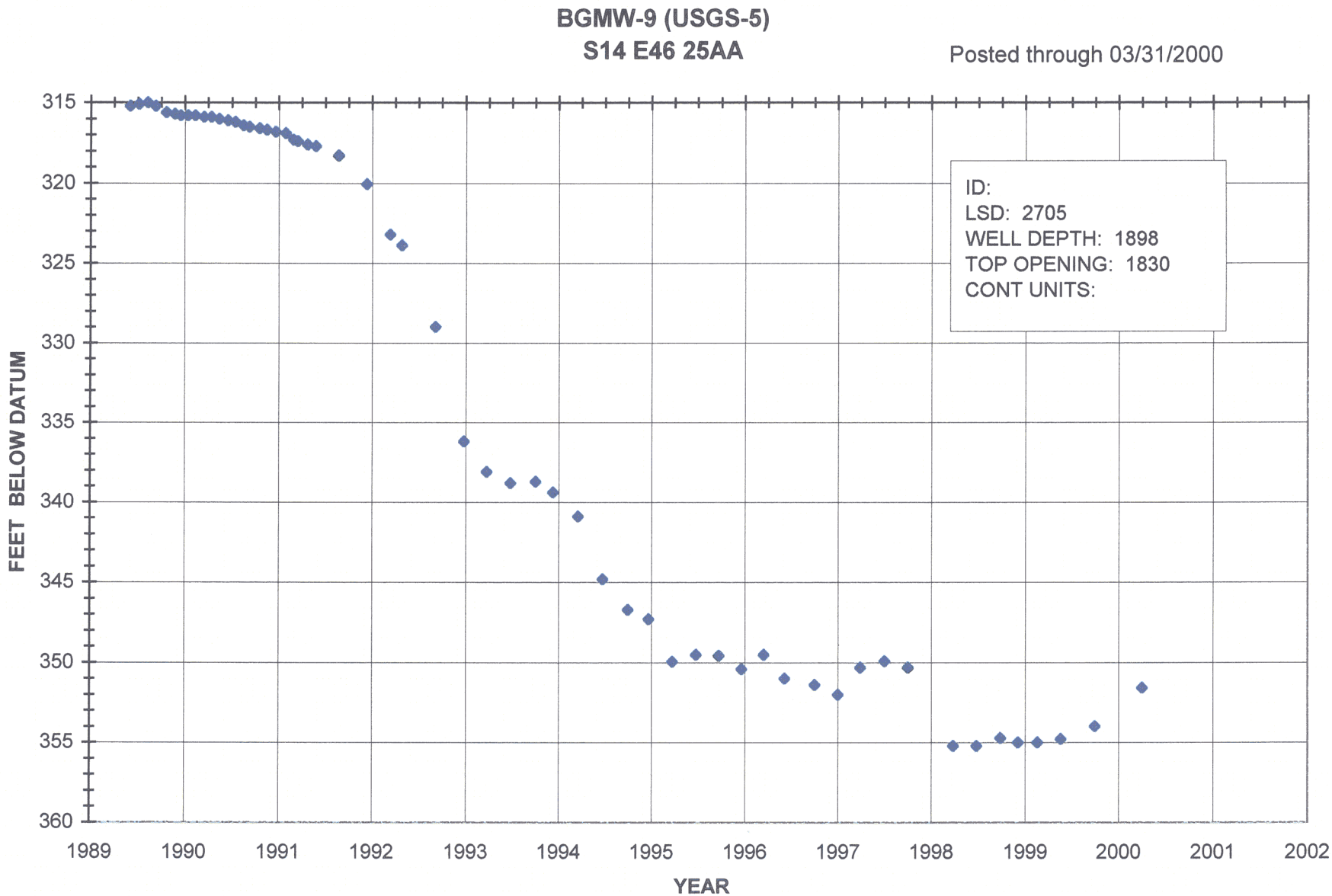

BGMW-5 (MW-3)
S14 E47 08CB
Posted through 03/31/2000
FEET BELOW LAND SURFACE
354
356
358
360
362
364
366
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
YEARS
ID:
LSD: 3220
WELL DEPTH: 733
TOP OPENING: 360
CONT UNITS:



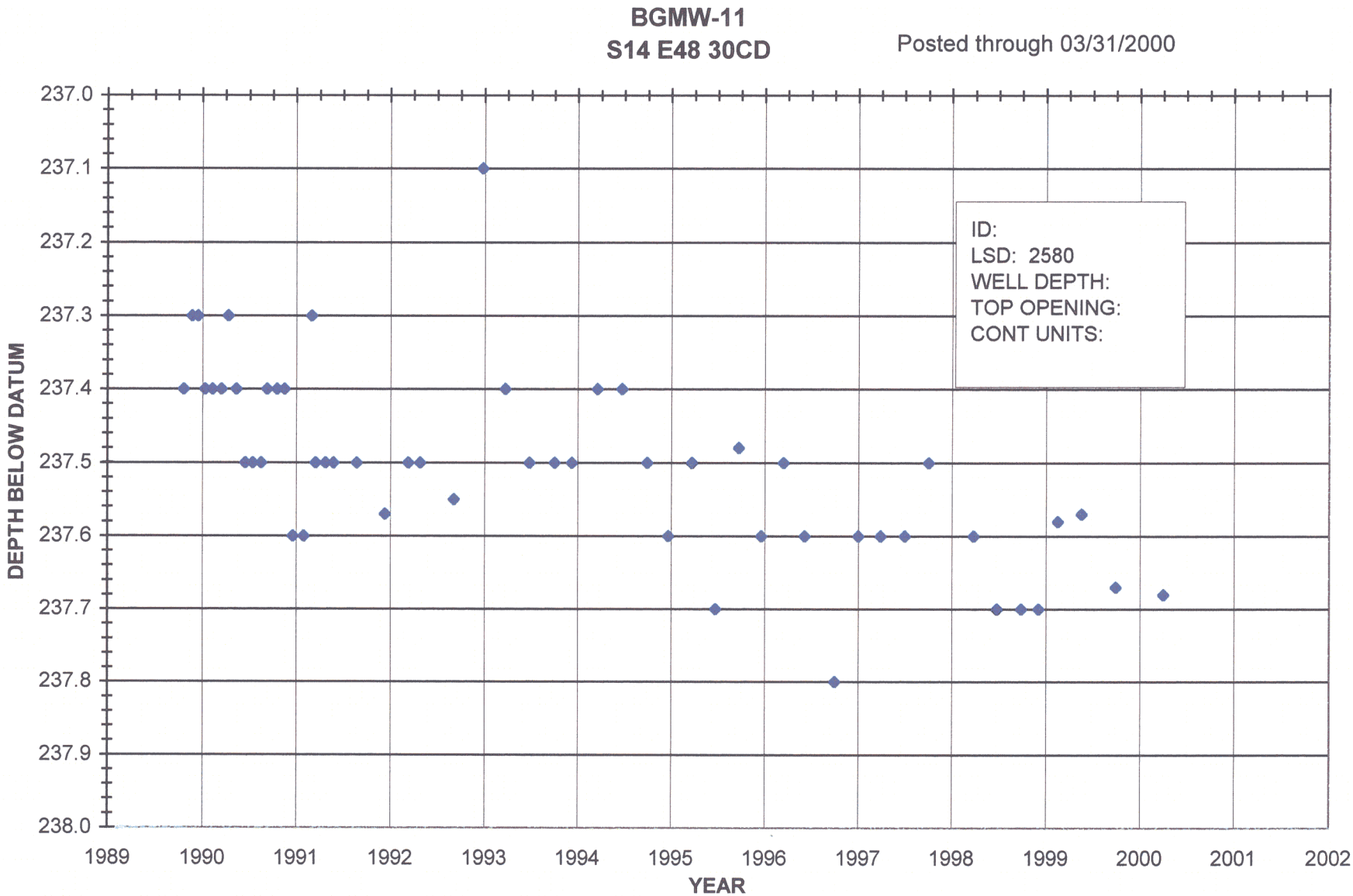
Hydrograph of well MW-6



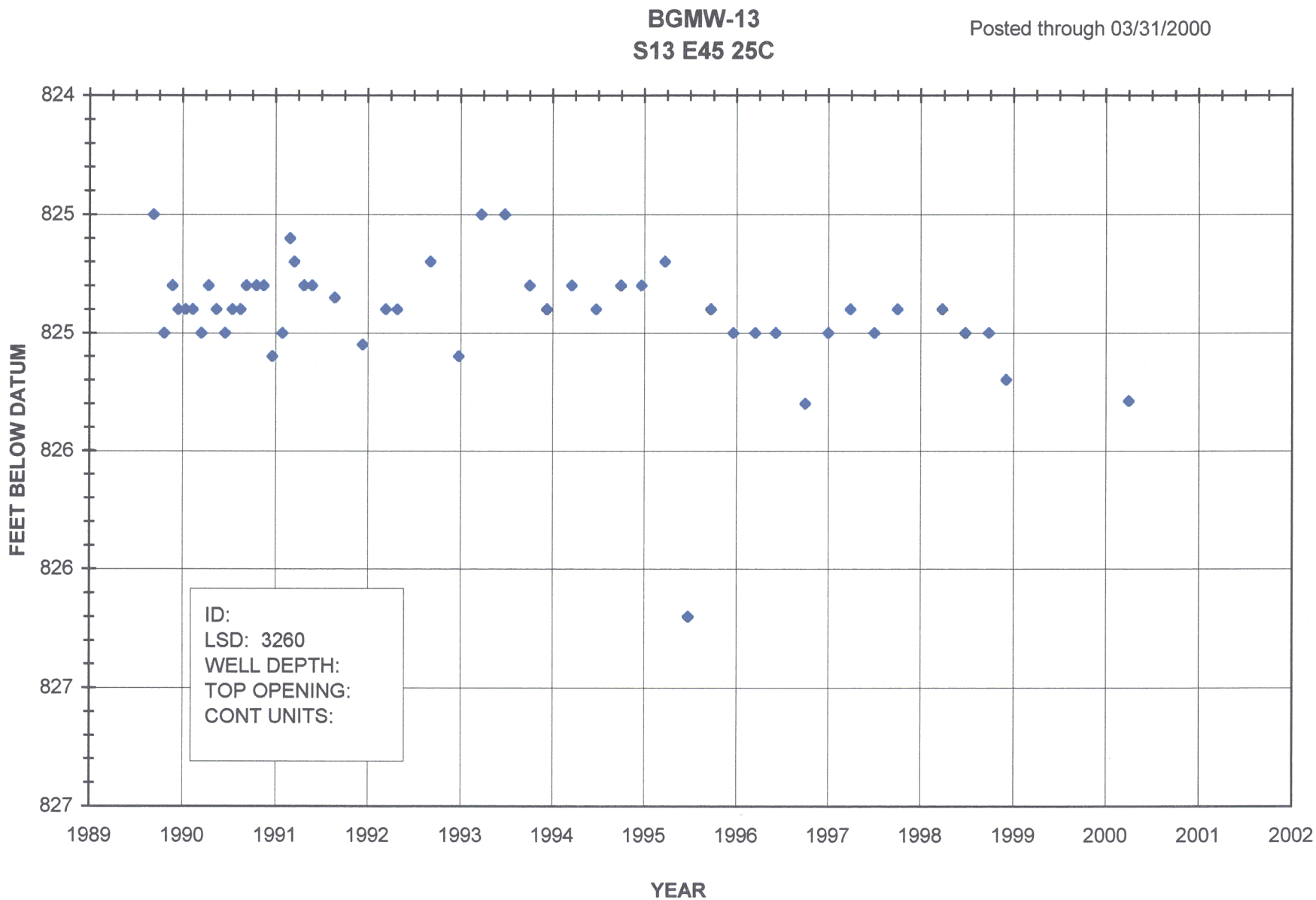
Hydrograph of well MW-8



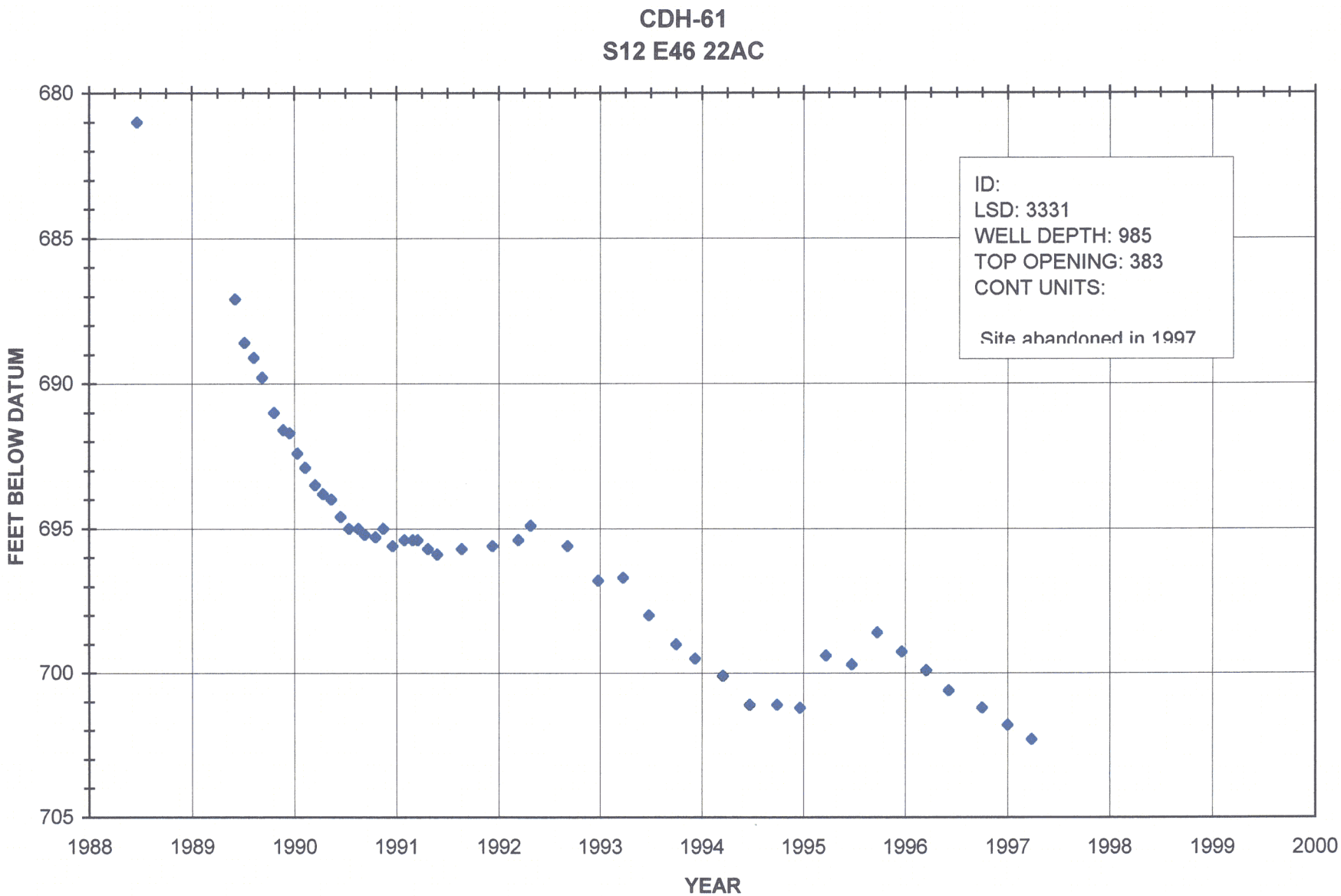
Hydrograph of well MW-9



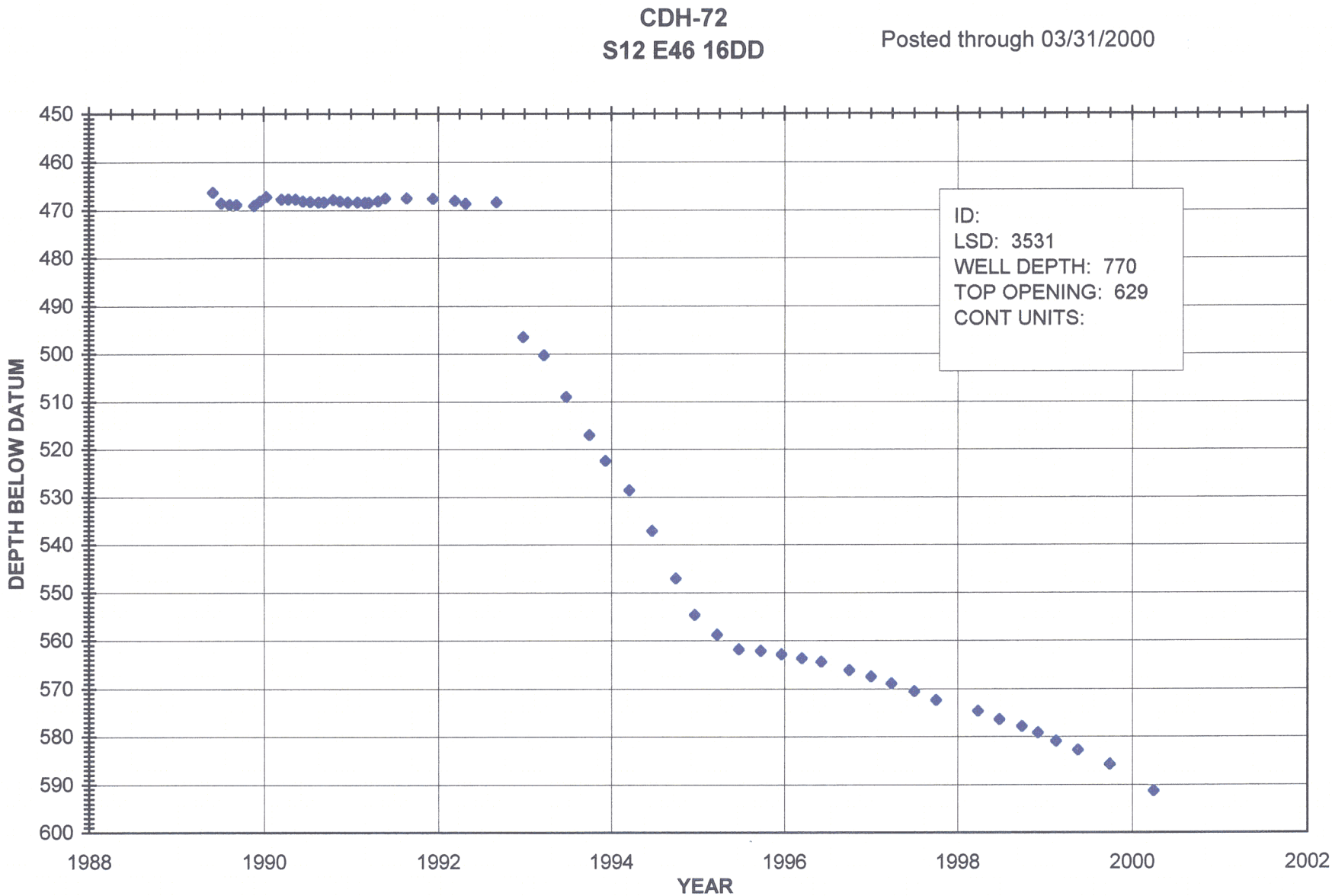
Hydrograph of well MW-11



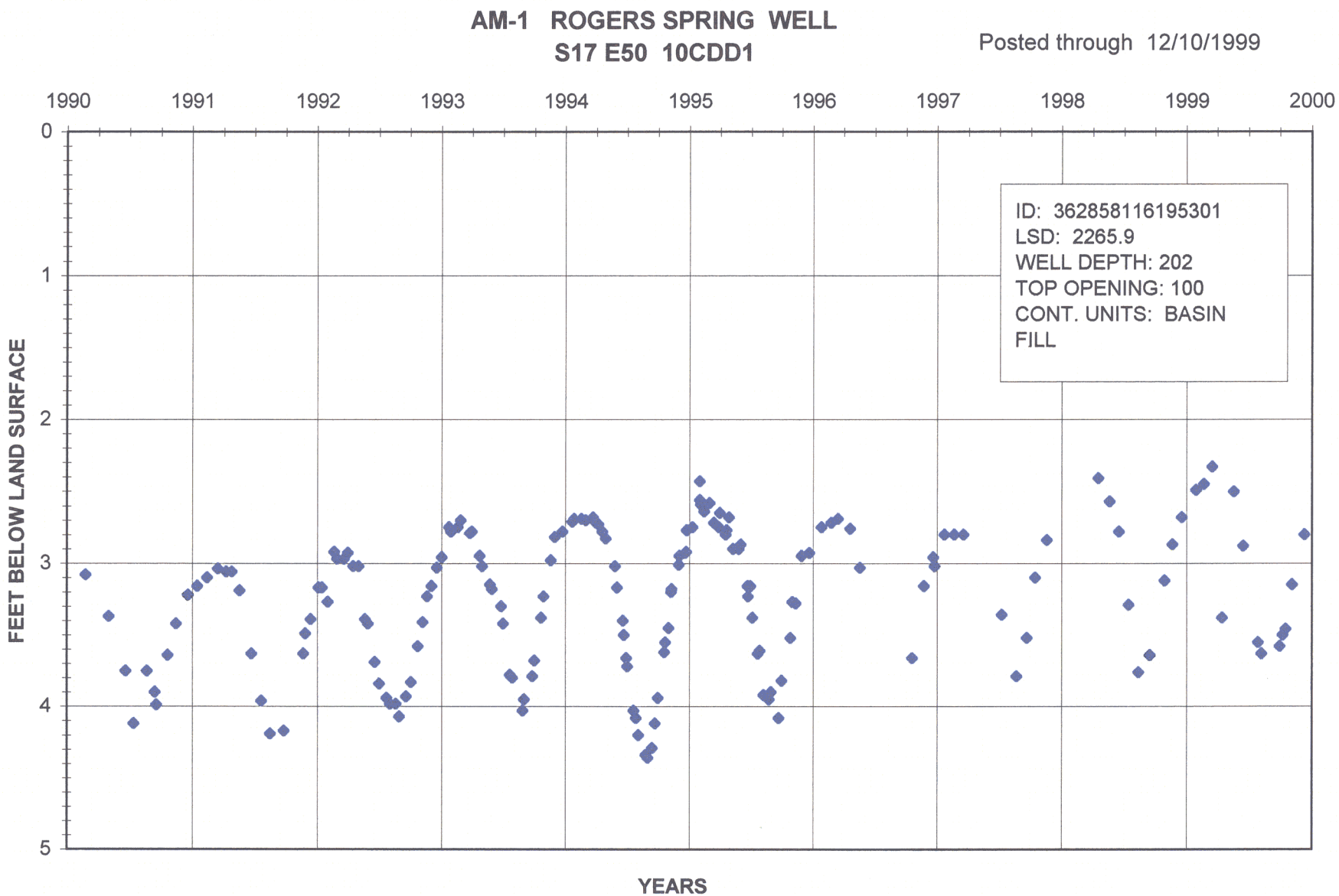
Hydrograph of well MW-13



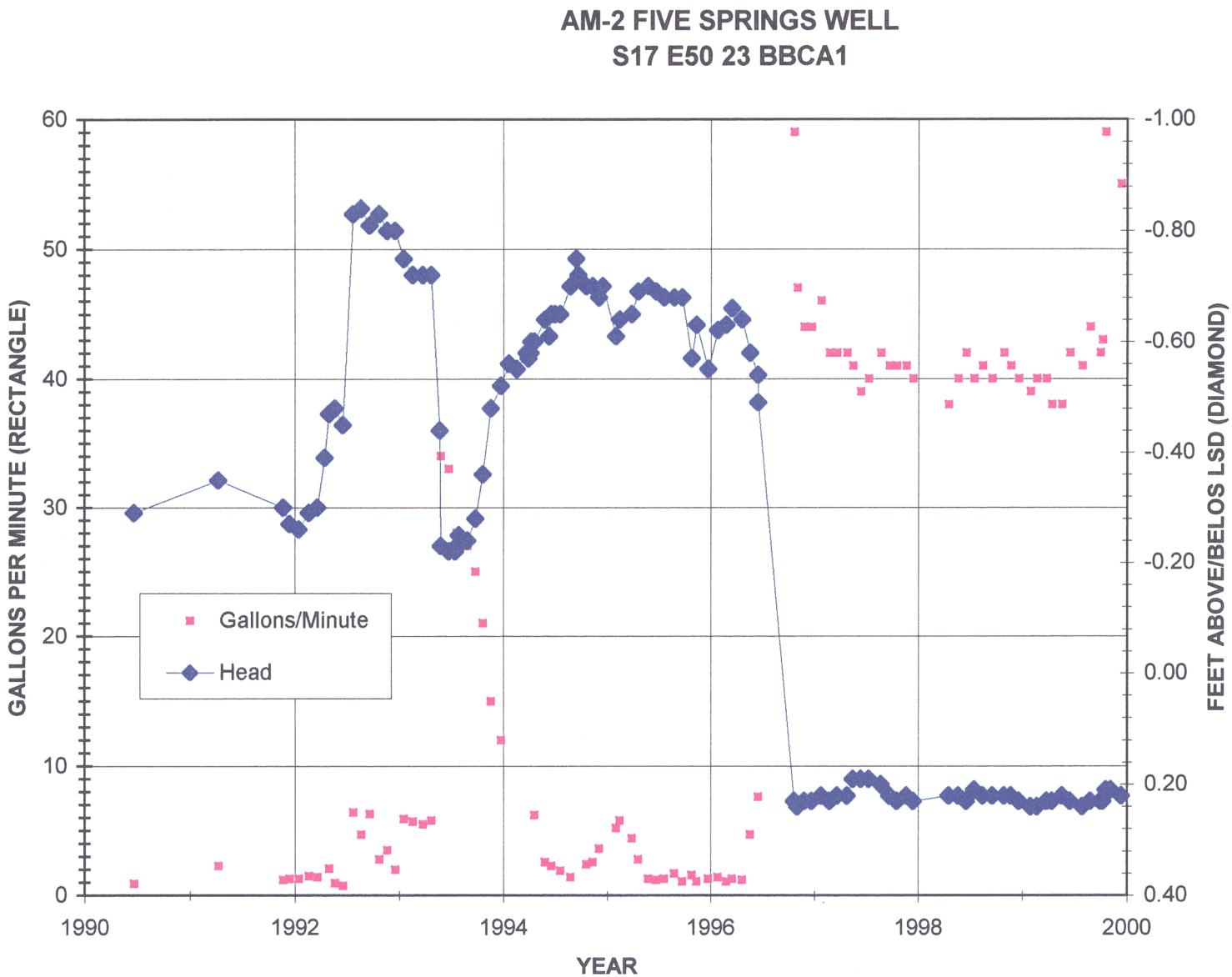
Hydrograph of well CDH-62



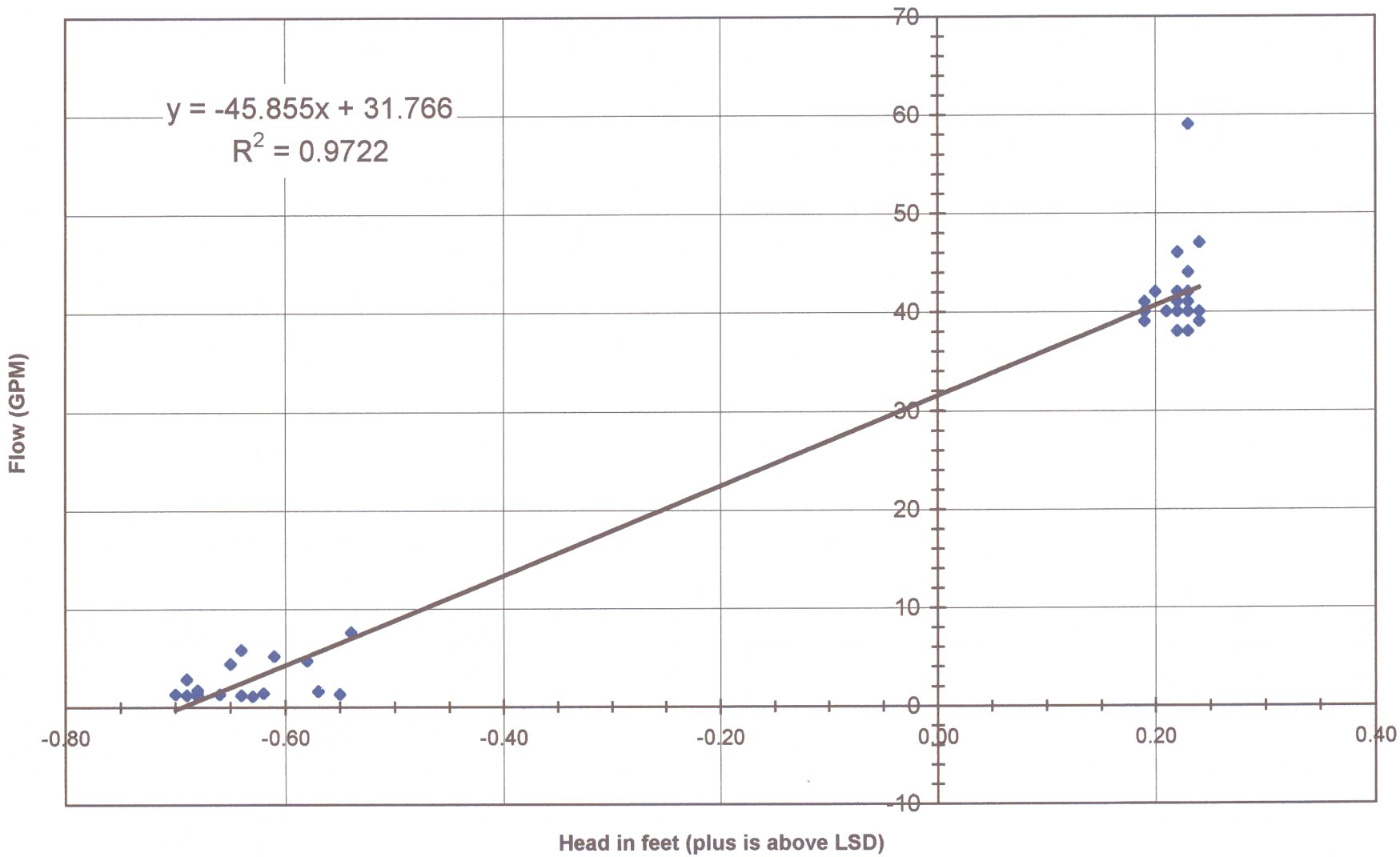
Hydrograph of well CDH-72



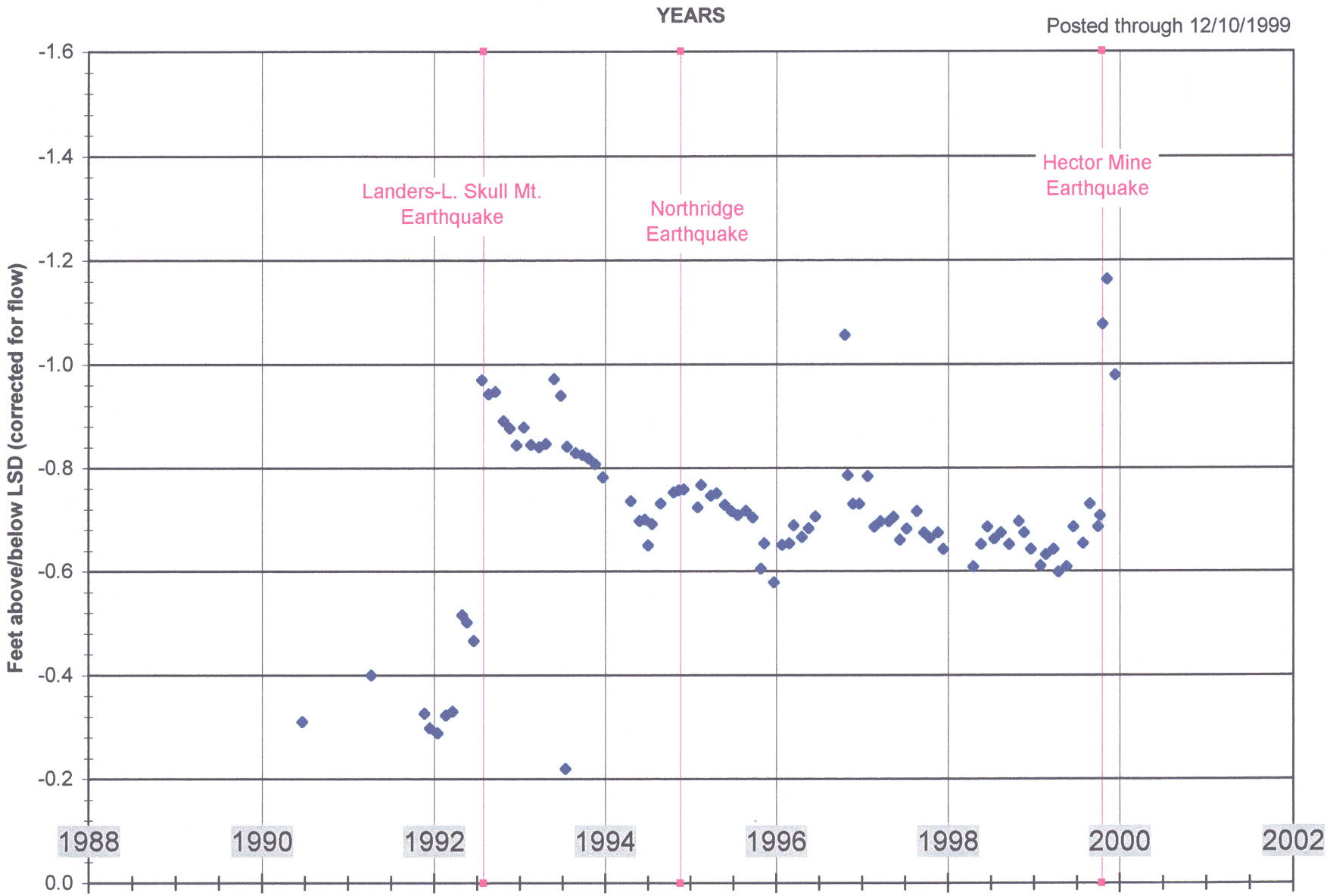
Hydrograph of well AM-1



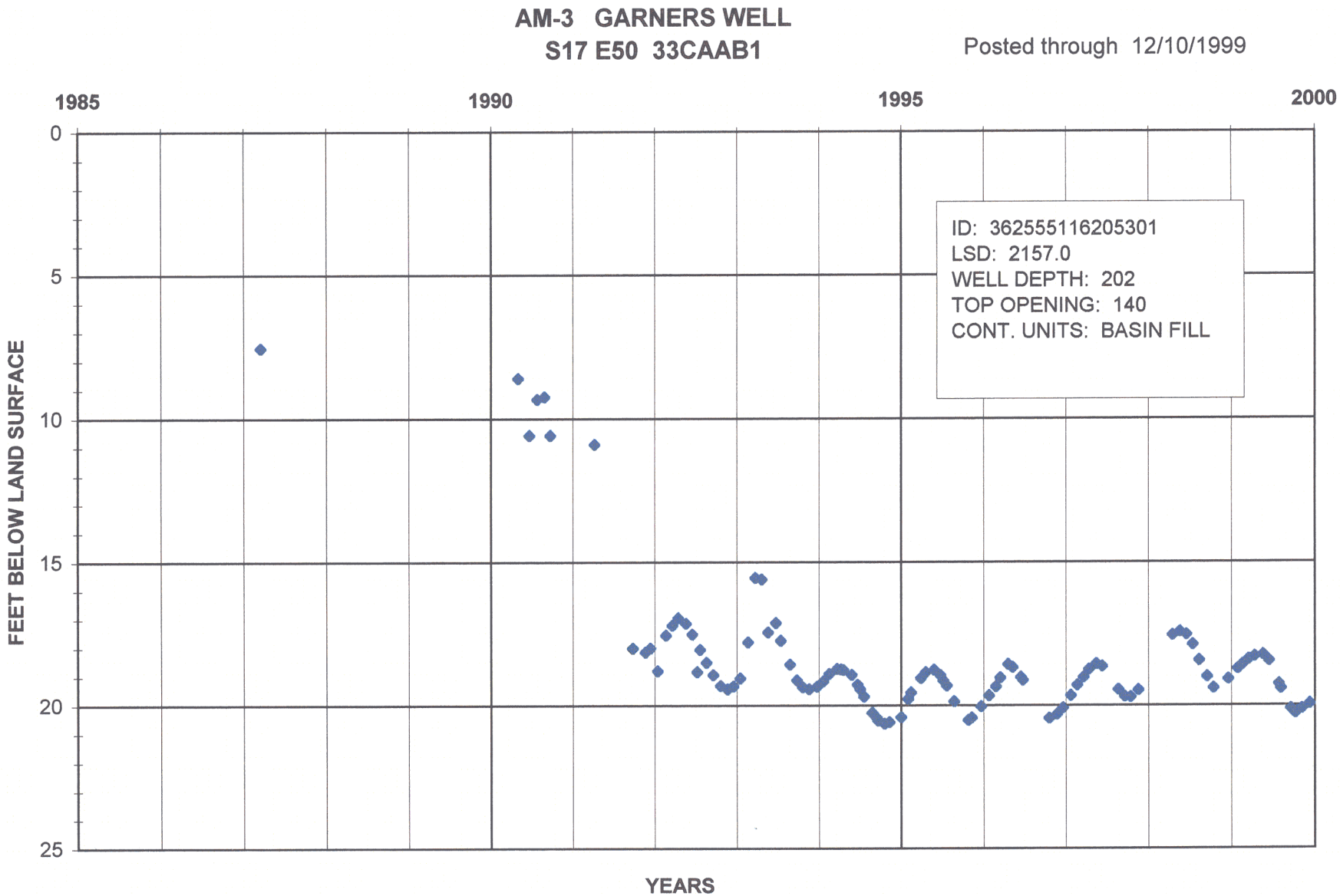
Hydrograph of well AM-2 (Five Springs Well) showing head and discharge



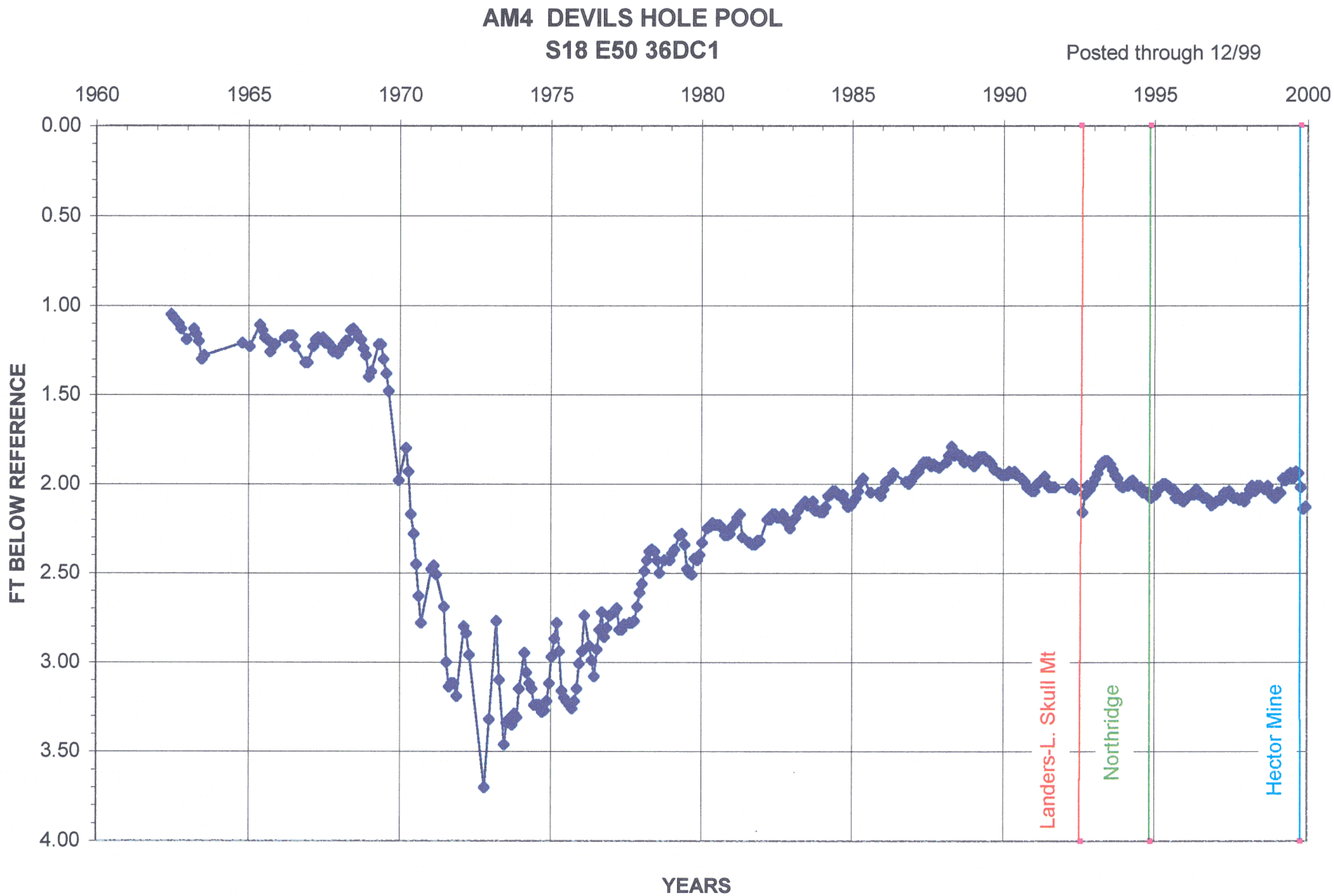
Relation between head and flow, well AM-2 (Five Springs well)

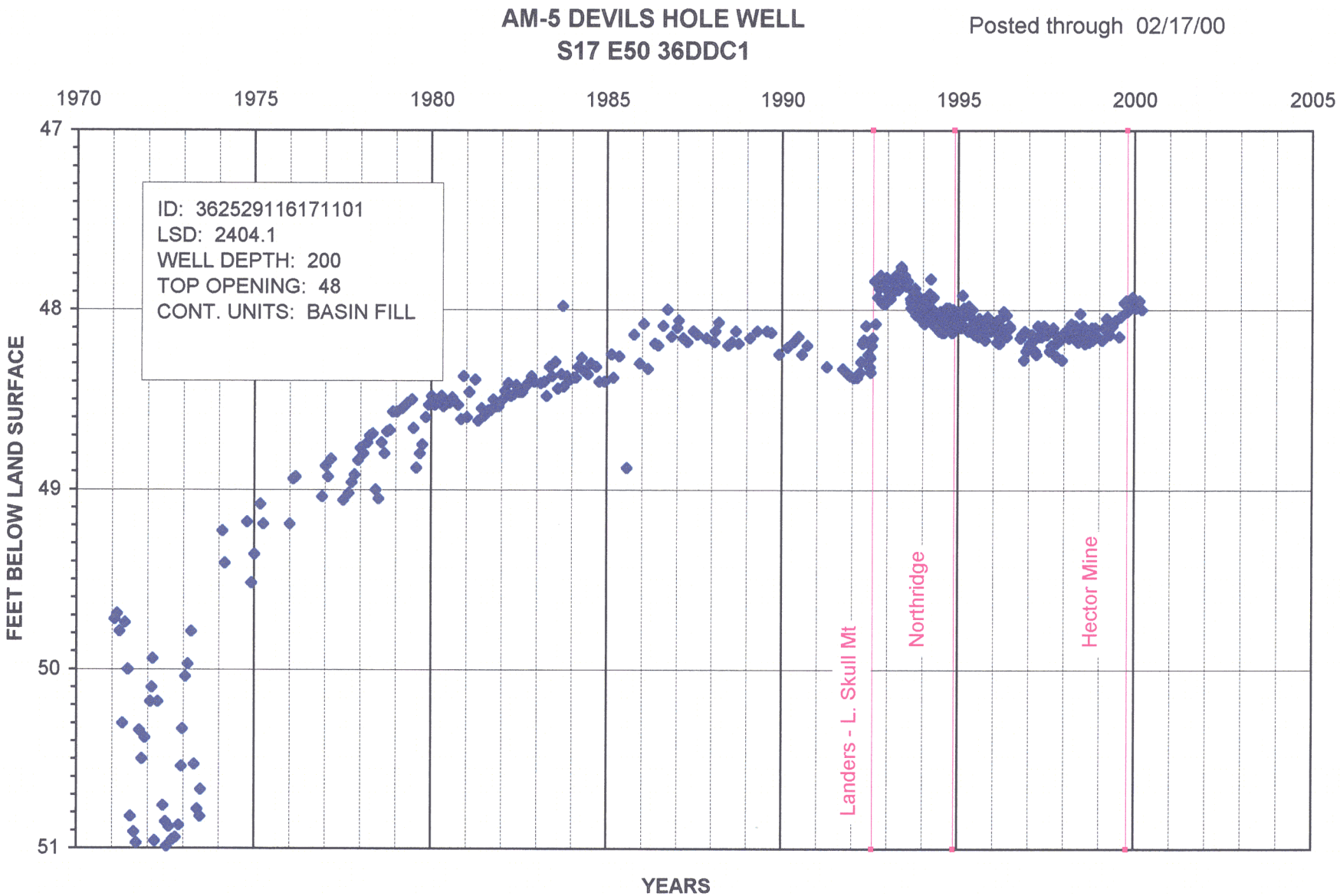


Hydrograph showing reconstructed "shut in" head,
Well AM-2 (Five Springs well)

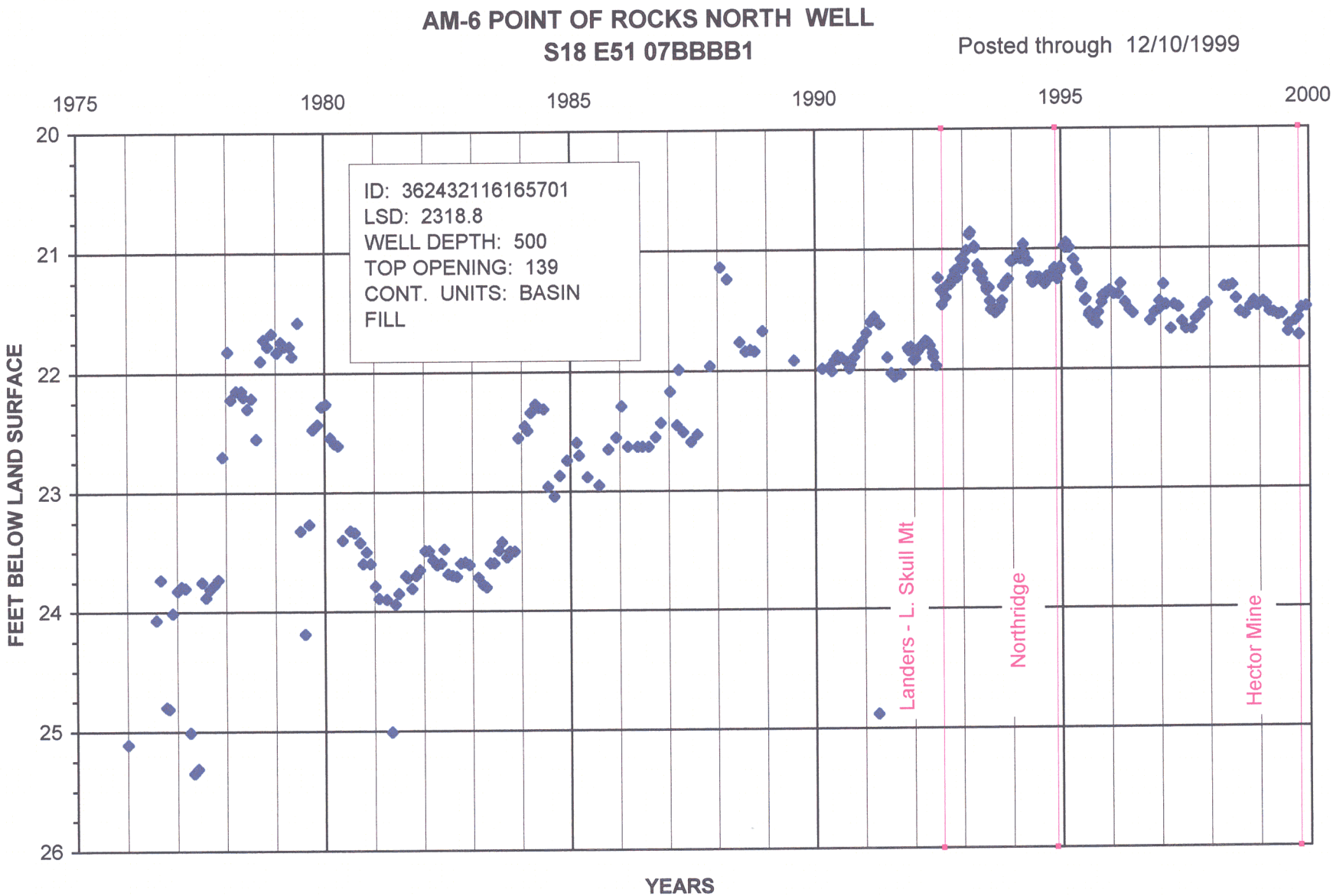


Hydrograph of well AM-3

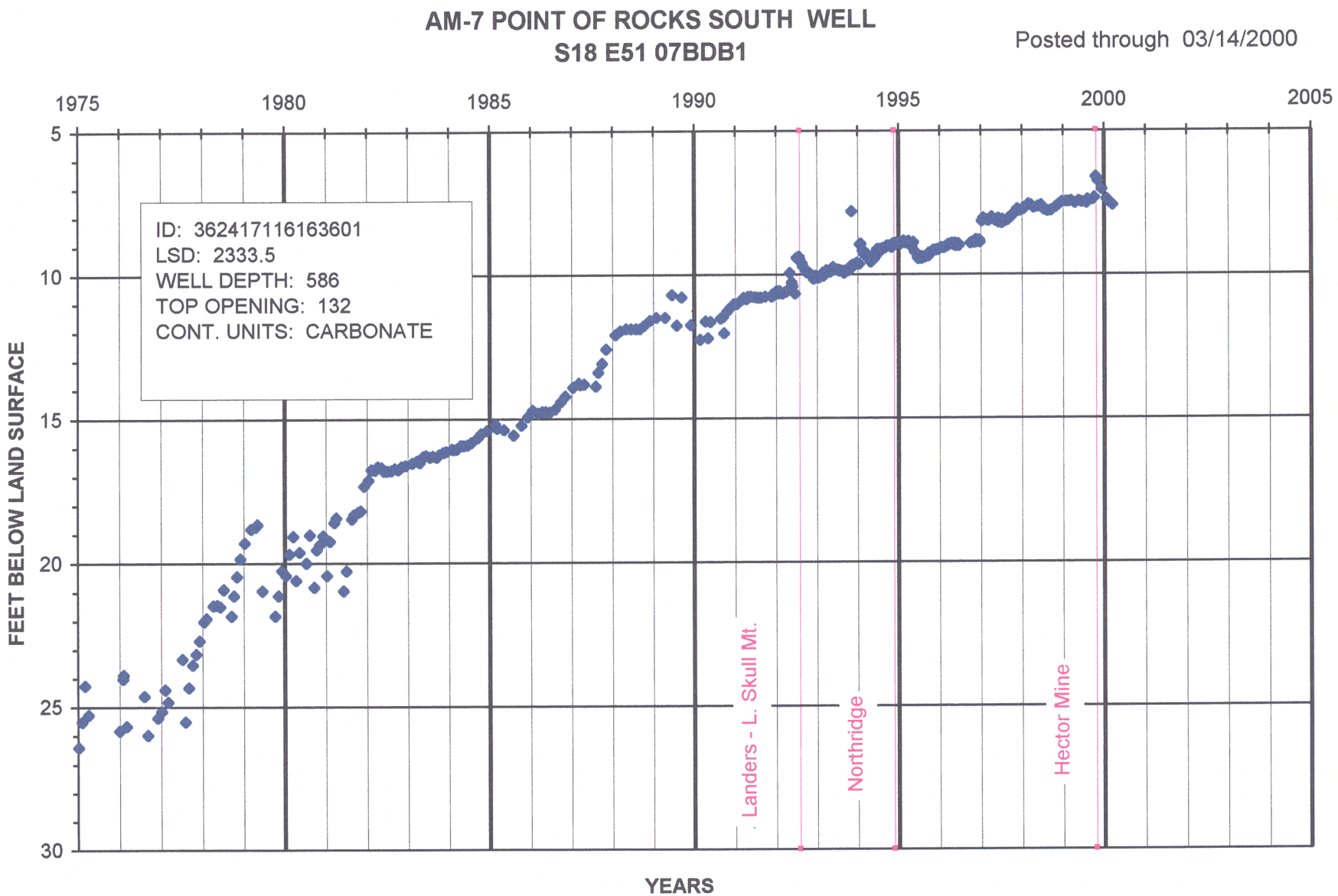

AM4 DEVILS HOLE POOL
S18 E50 36DC1
Posted through 12/99
1960
1965
1970
1975
1980
1985
1990
1995
2000
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
FT BELOW REFERENCE
YEARS
Landers-L. Skull Mt
Northridge
Hector Mine



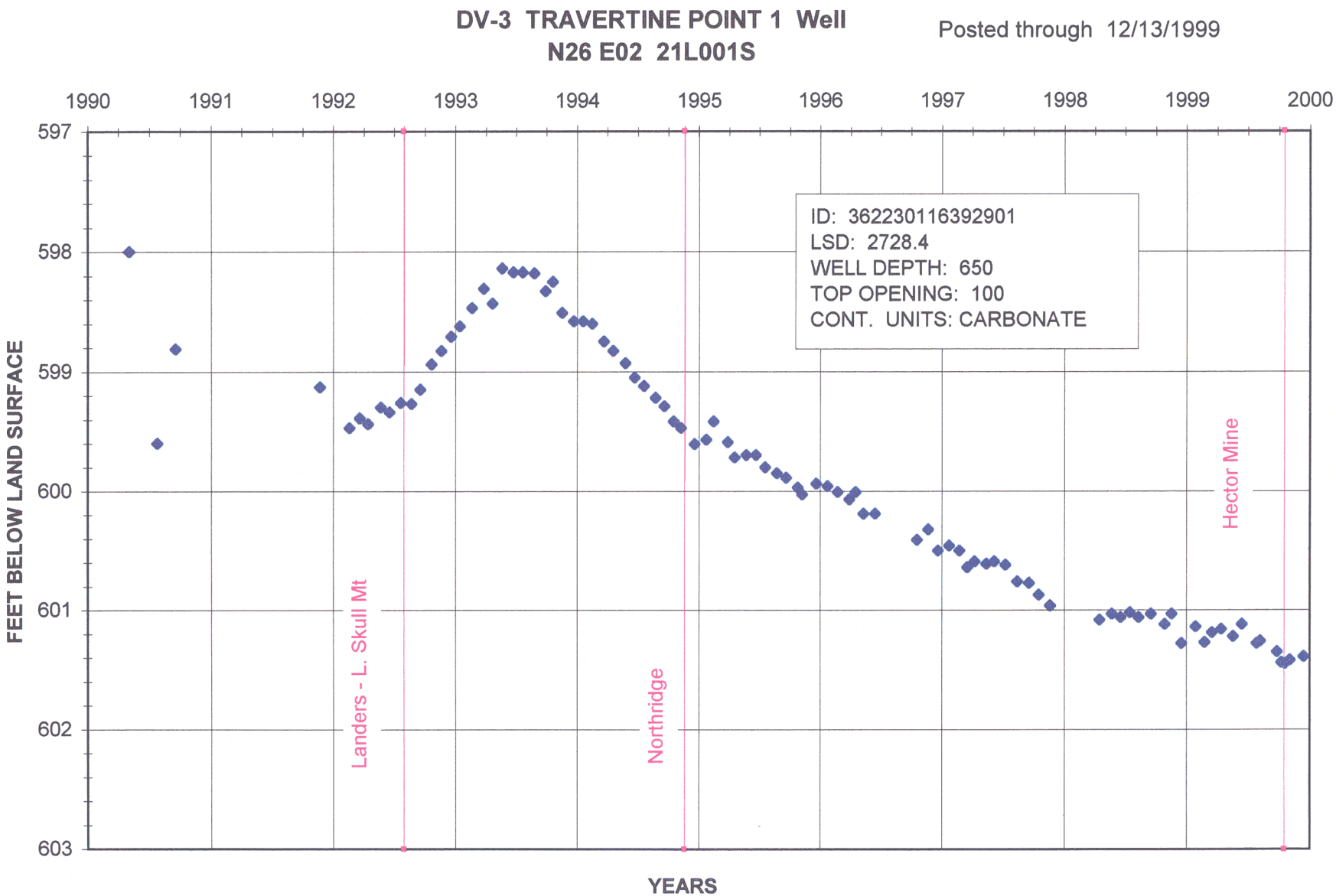
Hydrograph of well AM-5



Hydrograph of well AM-6

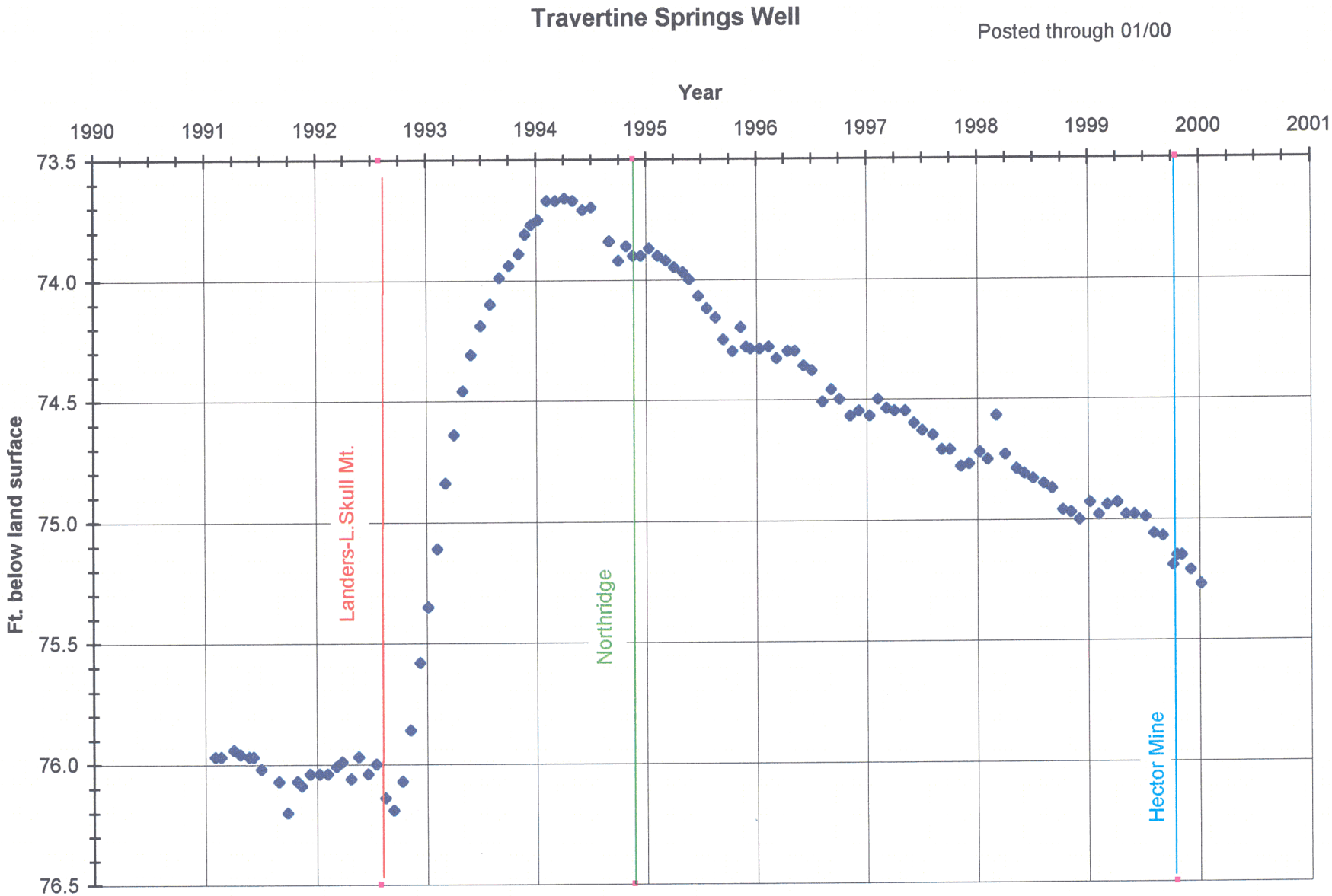


Hydrograph of well AM-7

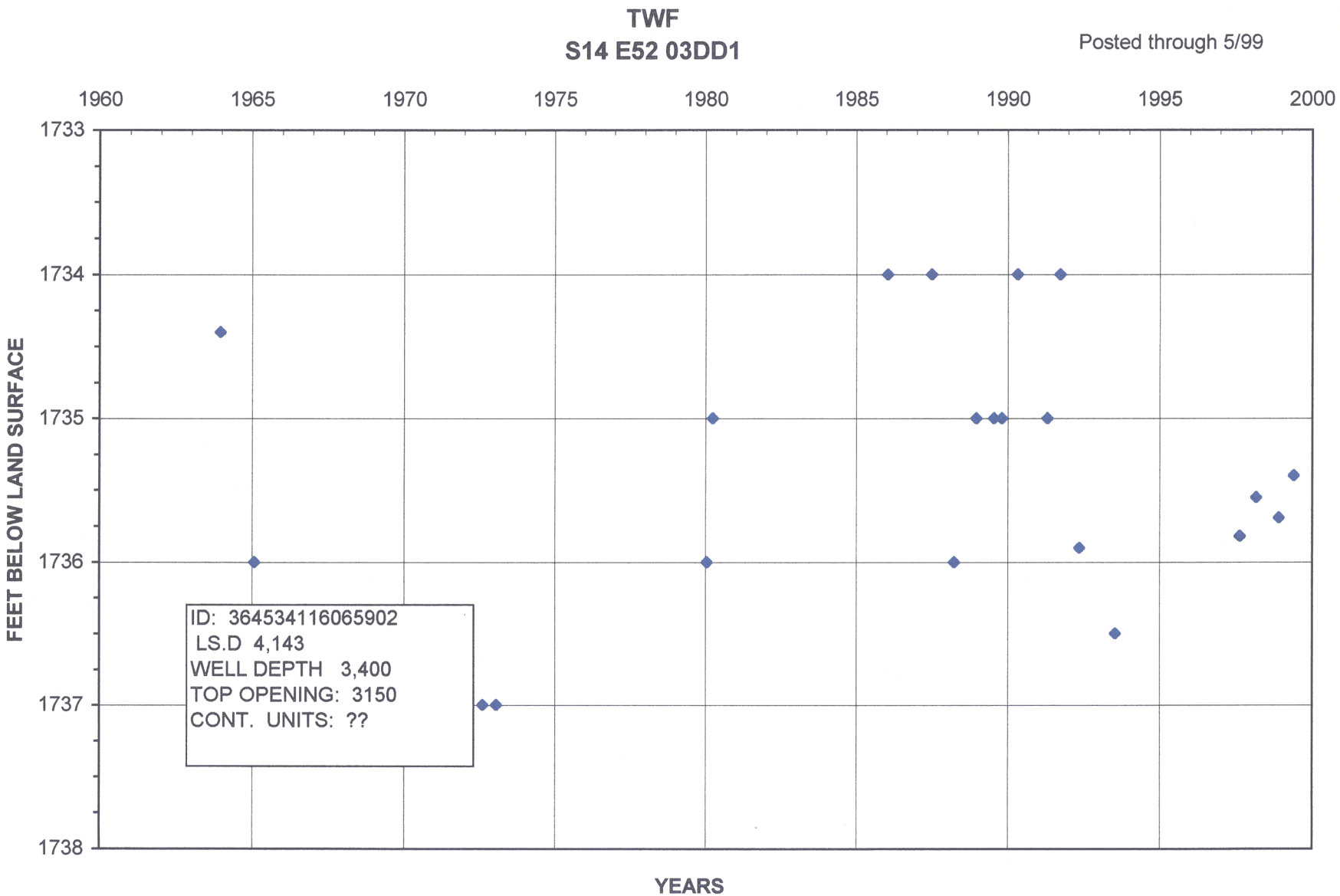


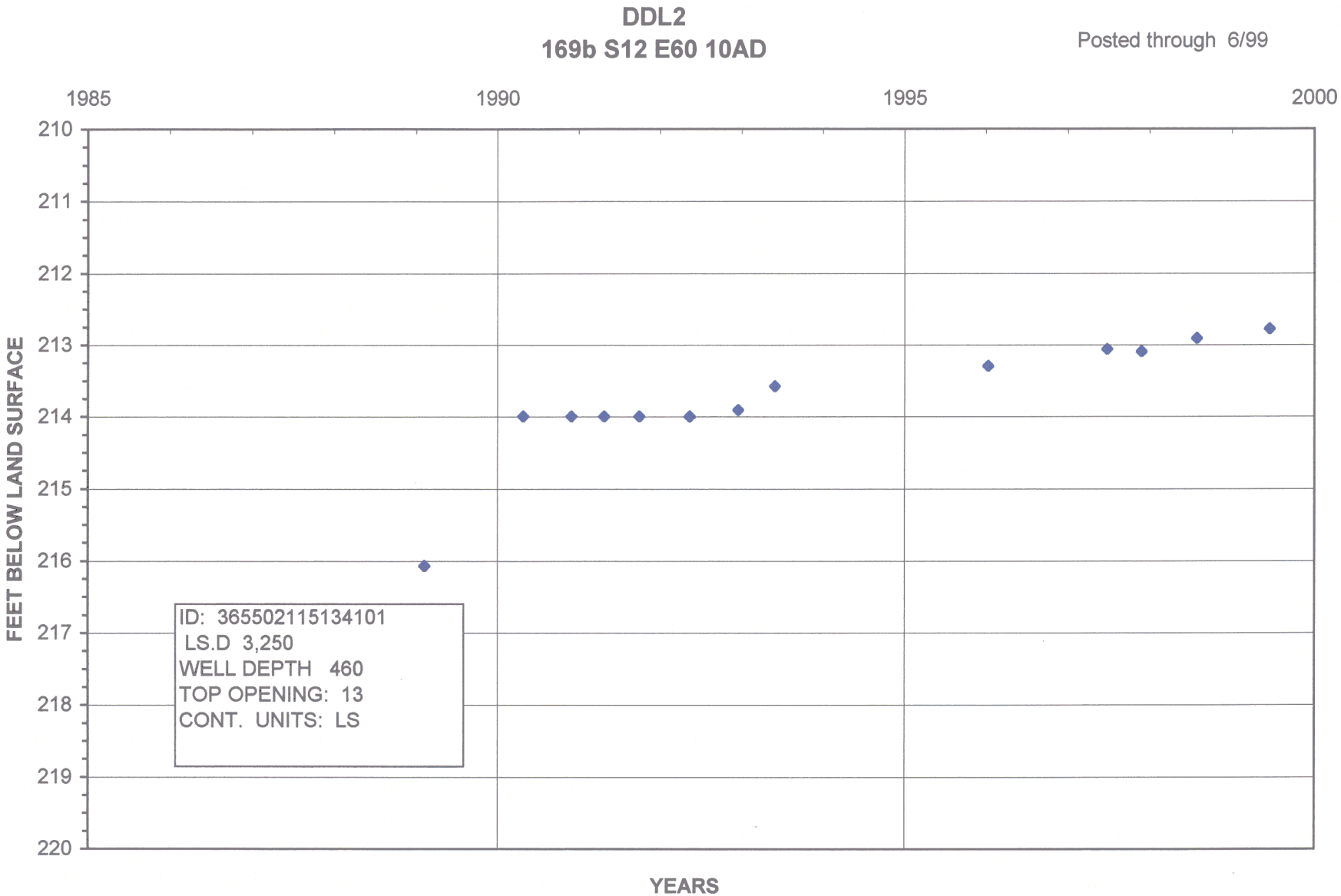
Hydrograph of well DV-3

Appendix VI

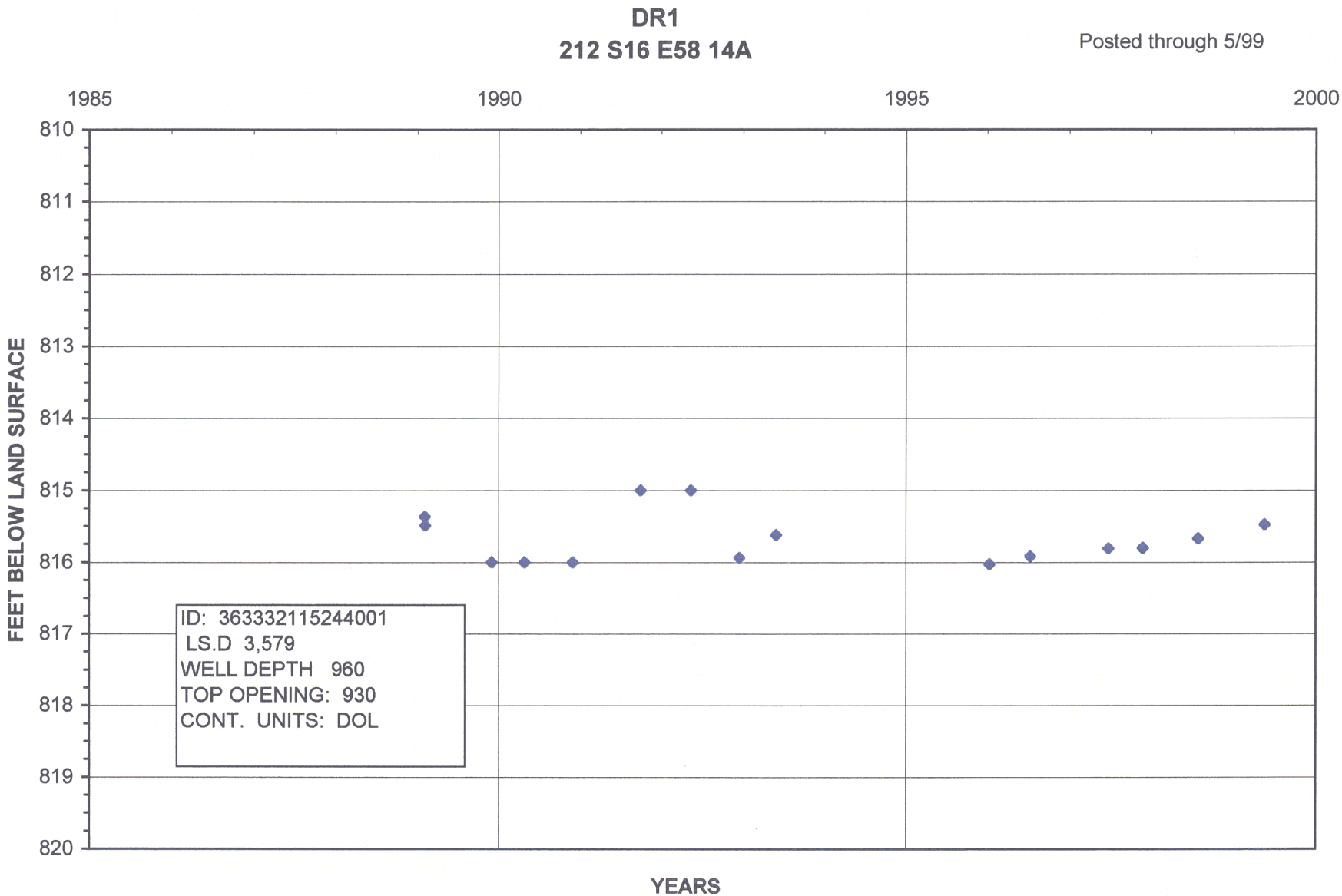


Hydrograph of Travertine Springs well

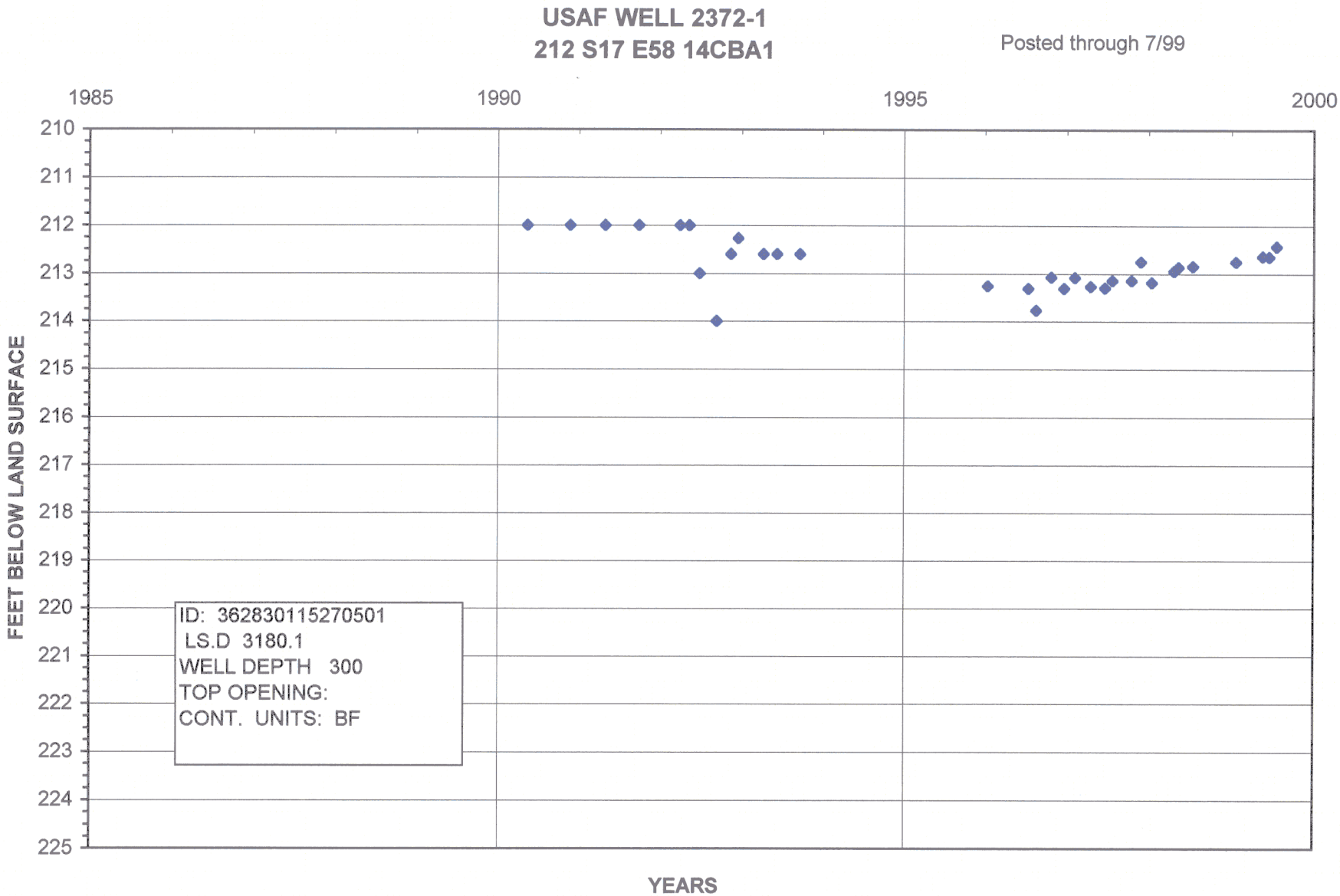

TWF
S14 E52 03DD1
Posted through 5/99
1960
1965
1970
1975
1980
1985
1990
1995
2000
1733
1734
1735
1736
1737
1738
FEET BELOW LAND SURFACE
YEARS
ID: 364534116065902
LS.D 4,143
WELL DEPTH 3,400
TOP OPENING: 3150
CONT. UNITS: ??



Hydrograph of well DDL-2



Hydrograph of well DR-1



Hydrograph of USAF well 2372-1

Table A.VI-1 Water-level data used to calculate net change 1993-1999

Site No.	HA	Loc Name	DATE-93	WL	DATE-99	WL	Net Change	YEARS
S14E5205DD1	160	TW-F	07/21/1993	1736.50	05/27/1999	1735.90	0.60	5.9
S16E5309AC1	225	ARMY-6A	06/21/1993	1031.80	05/13/1999	1032.88	-1.08	5.9
S16E5305ADB1	225	MV-1			02/25/1999	784.73		
S15E5024A1	226	RV-1	02/10/1993	678.1	02/25/1999	677.06	1.04	6.0
S13E5131B1	227A	J-11	02/02/1993	1040.57	02/17/1999	1040.39	0.18	6.0
S14E5006A1	227A	J-12	02/08/1993	739.44	02/18/1999	740.08	-0.64	6.0
S13E5019C1	227A	J-13	02/08/1993	927.21	02/22/1999	928.33	-1.12	6.0
S12E5033A1	227A	JF-1	02/01/1993	1161.27	02/03/1999	1161.11	0.16	6.0
S13E5018B1	227A	JF-2	02/15/1993	995.2	02/10/1999	995.27	-0.07	6.0
S13E4914A1	227A	JF-2A	03/16/1993	1186.87	03/03/1999	1185.13	1.74	6.0
S14E5006D1	227A	JF-3	02/09/1993	709.88	02/03/1999	710.12	-0.24	6.0
S12E4807ADD1	229	CF-1A	02/10/1993	161.4	02/23/1999	171.45	-10.05	6.0
S13E4827C1	229	CF-2	02/18/1993	603.74	02/02/1999	603.67	0.07	6.0
S15E4801AAA1	229	CF-3			02/25/1999	331.65		
S14E4732DA1	230	AD-1	02/10/1993	269.66	02/23/1999	269.62	0.04	6.0
S15E4924ABB1	230	AD-2	02/19/1993	324.31	02/25/1999	325.02	-0.71	6.0
S15E5018CCDB1	230	AD-2A	02/19/1993	341.85	02/25/1999	341.93	-0.08	6.0
S16E4805CAB1	230	AD-3A	02/19/1993	120.42	02/23/1999	132.1	-11.68	6.0
S16E5007CABB1	230	AD-4A	02/19/1993	117.39	02/23/1999	119.7	-2.31	6.0
S16E4918DCCA1	230	AD-5	02/19/1993	118.52	02/23/1999	127.61	-9.09	6.0
S16E5127BAA3	230	AD-6	02/16/1993	41.48	02/03/1999	41.62	-0.14	6.0
S17E4801AB2	230	AD-7A	02/19/1993	63.13	02/23/1999	69.55	-6.42	6.0
S17E5208CDB1	230	AD-8	02/19/1993	34.73	02/25/1999	35.19	-0.46	6.0
S17E4915BBBB1	230	AD-9	02/19/1993	70.53	02/23/1999	80.81	-10.28	6.0
026N005E05E001S	230	AD-10	02/19/1993	8.2	02/22/1999	12.18	-3.98	6.0
S19E5001BBD1	230	AD-11	02/25/1993	226.08	02/16/1999	218.15	7.93	6.0
S18E5134CBD1	230	AD-12	02/19/1993	80.57	02/16/1999	80.88	-0.31	6.0
025N004E21M001S	230	AD-13	02/18/1993	382.3	02/18/1999	373.57	8.73	6.0
025N005E14M001S	230	AD-14	02/18/1993	3.35	02/23/1999	2.81	0.54	6.0
S17E5010CDD1	230	AM-1	02/16/1993	2.75	02/19/1999	2.45	0.3	6.0
S17E5010CDD1	230	AM-1A	02/16/1993	1800	02/22/1999	1600	200	6.0
S17E5023BBCA1	230	AM-2	02/16/1993	-0.72	02/19/1999	0.24	-0.96	6.0
S17E5033CAAB1	230	AM-3	02/19/1993	17.78	02/18/1999	18.56	-0.78	6.0
S17E50	230	AM-4	02/16/1993	1.86	02/15/1999	2.05	-0.19	6.0
S17E5036DDC1	230	AM-5	02/16/1993	47.84	02/18/1999	48.1	-0.26	6.0
S18E5003ADBA1	230	AM-5A	02/16/1993	2900	02/22/1999	3000	100.00	6.0
S18E5107BBBB1	230	AM-6	02/19/1993	20.88	02/19/1999	21.47	-0.59	6.0
S18E5107BDB1	230	AM-7	02/19/1993	9.96	02/19/1999	7.47	2.49	6.0
S18E5119ACB1	230	AM-8	02/16/1993	1000.00	02/22/1999	980.00	-20.00	6.0
S13E4610DB1	230	BGMW-1	03/22/1993	617.70	02/16/1999	620.26	-2.56	5.9
S13E4615DB	230	BGMW-2	03/22/1993	502.90	02/16/1999	503.23	-0.33	5.9
S13E4616AD	230	BGMW-3	03/22/1993	661.70	02/16/1999	662.02	-0.32	5.9
S13E4635DA	230	BGMW-4	03/22/1993	417.00	02/16/1999	417.32	-0.32	5.9
S14E4608CB	230	BGMW-5	03/22/1993	356.70	02/16/1999	356.78	-0.08	5.9
S14E4626BA	230	BGMW-6	03/22/1993	281.90	02/16/1999	281.91	-0.01	5.9
S14E4825BD	230	BGMW-8	03/22/1993	340.00	02/16/1999	340.20	-0.20	5.9
S14E4625AA	230	BGMW-9	03/22/1993	338.10	02/16/1999	354.99	-16.89	5.9
S14E4830CD	230	BGMW-11	03/22/1993	237.40	02/16/1999	237.57	-0.17	5.9
S13E4525C	230	BGMW-13	03/22/1993	824.50	02/16/1999	825.02	-0.52	5.9
S12E4622AC	230	CDH-61	03/22/1993	697.7	03/27/1997	702.3	-4.60	4.0
S12E4616DD	230	CDH-72	03/22/1993	500.3	02/16/1999	580.89	-80.59	5.9
S13E4735BDBA1	230	MR-3	03/11/1993	367.60	09/30/1998	370.60	-3.00	5.6
027N001E23BS01S	243	DV-1	02/18/1993	200.00	02/18/1999	190.00	-10.00	6.0
026N002E13FS01S	243	DV-2	02/18/1993	1.90	02/18/1999	0.90	-1.00	6.0
026N003E21L001S	243	DV-3	02/18/1993	598.47	02/23/1999	601.27	-2.80	6.0
027N001E24E001S	243	TRAV-W	02/04/1993	75.11	02/04/1999	74.98	0.13	6.0

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

DEVA D-253, August 2005